THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE PERMANENT SECRETARY OF THE GEOLOGICAL SOCIETY.

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Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare ; atque non disputando adversarium, sed opere naturam vincere ; denique non belle et probabiliter opinari, sed certo et ostensive scire ; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant —*Novum Organum, Præfatio.*

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VOLUME THE SEVENTY-FIFTH,

FOR 1919.



LONDON:
LONGMANS, GREEN, AND CO.
PARIS: CHARLES KLINCKSIECK, 11 RUE DE LILLE.
SOLD ALSO AT THE APARTMENTS OF THE SOCIETY,
MCMXX.

# List
OF THE
# OFFICERS
OF THE
# GEOLOGICAL SOCIETY OF LONDON.

Elected February 21st, 1919.

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George William Lamplugh, F.R.S.

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Prof. John Edward Marr, M.A., Sc.D., F.R.S.
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Sir Jethro Teall.
Mr. S. H. Warren.
Prof. W. W. Watts.

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No. 300—August 17th, 1920.

# LIST OF THE FOSSILS FIGURED AND DESCRIBED IN THIS VOLUME.

| Name of Species. | Formation. | Locality. | Page |
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| | LAMELLIBRANCHIATA. | | |
| *Cyrtodaria siliqua*, fig. 4 ...... | Scandinavian Drift ......... | Warren-House Gill ............ | 194–96 |
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## ERRATUM ET OMISSUM.

*Page* 10, nineteenth line from the top, insert a comma after 'feet.'

The scale of the plan of Cambridge, etc. (p. 205) is wrongly stated as 1 : 126,720. It should read, 1 : 31,680.

# EXPLANATION OF THE PLATES.

## PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES

### BESIDES THOSE IN THE PLATES.

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Vol. LXXV. No. 297.
Part 1.

THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY.



EDITED BY

THE PERMANENT SECRETARY.

[With Three Plates, illustrating Dr. A. Smith Woodward's and Mr. C. J. Gilbert's Papers.]

January 17th, 1920.

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*Price Seven Shillings and Sixpence.*

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Sir Jethro Teall.
Mr. S. H. Warren
Prof. W. W. Watts.

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## ORDINARY MEETINGS OF THE GEOLOGICAL SOCIETY
### TO BE HELD AT BURLINGTON HOUSE.
### SESSION 1919-1920.

1920.

| | | |
|---|---|---|
| Wednesday, | January | 21* |
| ,, | February (*Anniversary Meeting*, Friday, February 20th) | 4*—25* |
| ,, | March | 10—24* |
| ,, | April | 21* |
| ,, | May | 5 —19* |
| ,, | June | 9 —23* |

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

# PROCEEDINGS

OF THE

# GEOLOGICAL SOCIETY OF LONDON.

## SESSION 1918-19.



November 6th, 1918.

Mr. G. W. LAMPLUGH, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The PRESIDENT read a communication that he had received from Prof. CHARLES BARROIS, D.Sc., F.M.G.S., in reply to congratulations sent on the occasion of the evacuation of Lille by the enemy forces.

A Discussion on the Antarctic Ice-Cap and its Borders was introduced by Sir DOUGLAS MAWSON, D.Sc., B.E., F.G.S.

Sir Douglas Mawson said that, at the last Meeting of the Society, the subject of the Antarctic Ice-Cap was reviewed in its broader aspects, chiefly with the view of promoting a discussion among those specially interested in Glaciology. The present occasion had been reserved for the Discussion, and he proposed to show certain lantern-slides in order to bring the salient features freshly to mind.

Though much of the foundation of the Antarctic Ice-Cap is certainly elevated land, it is quite possible that elsewhere the dome rests upon a floor actually below sea-level. In any case it is most probable that the smooth ice-surface masks a very irregular rock-basement. The thickness of the ice may, therefore, be expected to be extremely variable, doubtless reaching a maximum of several thousands of feet.

An ice-formation of such magnitude introduces questions relating to the flow of its substance and the abrasion of its foundations which do not enter into the physics of ice-masses of smaller dimensions.

Here the static pressure on the lower zones of the ice may reach 1 ton per square inch. At the same time, the temperature may be so increased by ground heat as to be much higher than that prevailing above. As a consequence, when the ice-formation is very thick, a more plastic base must be admitted.

The outflow of the inland ice is principally deflected at the coastal margin into depressed areas outlining the heads of gulfs and bays. In such localities the rate of movement and the volume of ice entering the sea are both great. So great indeed, that extensive floating 'glacier-tongues' are a feature of such situations, often extending 40 to 50 miles from the shore.

Along other stretches of the coast less well placed for receiving contributions from the interior of the continent, the outflow is so much less that the destructive influences at work on reaching the sea easily maintain its boundaries at approximately the true coast-line.

As exceptions to this latter prevailing condition, however, there are known already two notable localities where the general overflow from the land maintains itself as an immensely thick floating structure extending far out over the sea—a veritable oceanic ice-cap. To this type of formation we apply Prof. Nordenskjöld's term 'shelf-ice.' The formations referred to are the Great Ross Barrier at the head of the Ross Sea, and the Shackleton Shelf off the coast of Queen Mary Land.

The former occupies what is really the head of the Ross Sea—a somewhat triangular area. From apex to base it measures 500 miles, with a base-length of about 400 miles. This great raft of ice presses forward to the open sea at the rate of a few hundred yards per annum. The available figures, quoted by David and Priestley, show that, at the present rate of advance, the ice now appearing at the sea-face must have left the inner extremity of the floating sheet at some time during the 7th century. A survey of the ice-cliff forming the sea-face indicates by its changing height that the Ross Barrier is of varying thickness. This has been explained by the presence, in localities where it is thickest, of the remnants of the massive-ice contribution received during its course from certain of the large tributary glaciers. The ice from these glaciers, in fact, constitutes a strong framework which stiffens and contains the more crumbling structure derived from the consolidation of the annual snowfall.

To a great extent this must certainly be so; but the influence of a varying snowfall, and the effect of violent periodic winds—a feature of the region—in sweeping the loose snow from certain areas and depositing it in other favoured localities, must be reckoned with. The snowfall is lighter on the eastern side than on the western. Furthermore, the snow tends to accumulate on the western side, owing to the fact that the winds regularly blow from the quarter south to east, and not from the west.

In the case of the Shackleton Shelf, this is the more remarkable, because it maintains itself as a pontoon stretching into the open sea, even across the drift of the prevailing ocean-current.

The deluge of ice, after descending to the sea, presses northwards as an integral whole, at first touching bottom at intervals, then forcing its way past several islands, eventually reaches an extreme distance of 180 miles from the land before it is mastered by the swell and currents of the Southern Ocean. It is somewhat triangular in form, with the apex out to sea. The base against the land, though not completely charted, extends in all probability for a distance of about 200 miles.

The main body of the shelf-ice advances rather slowly, but the Denman Glacier, which contributes to it, has a much more rapid movement, very well illustrated by the fact of its ploughing through the other shelf-ice with such force that a shatter-zone some miles wide is developed.

The wall of the shelf-ice on the west side offers an excellent example for study, as it is a section from the point of its departure from the land to its crumbling apex. In the case of the Ross Barrier, the cliff-face is a section across the direction of movement.

At the land end, the Shackleton Shelf, from the surface down, is hard glacier-ice breaking with a characteristic fracture. A few miles farther out, away from the influence of the winds descending from the land slopes, a nevé mantle commences to make its appearance over the original ice-formation. As one steams along the face away from the land, this capping is observed to increase steadily in thickness. The overburden of nevé is arranged in regular bands, each of which corresponds to a single year's addition. This being so, it is possible to make some sort of an estimate of the age of the formation.

The weight of these additions depresses the top of the original ice below the surface of the water. Though there is a regular annual addition above, it must not be imagined that the total thickness of the pontoon is correspondingly increased; for the solution of the lower surface by the sea has also to be reckoned with. Very often, however, in the nevé sections of glacier-tongues the cliff-face above the water is observed to stand higher than in the wholly ice zone at the land end. This is to be expected, on account of the lighter nature of the nevé ice added, there being a larger proportion of air sealed up in it.

The observed height above sea-level of Antarctic shelf-ice so far recorded ranges from about 20 to over 200 feet. A common figure is from 90 to 120 feet, suggesting a total thickness of 600 to 1000 feet.

Although the height of the cliff-face presented by shelf-ice gives some idea of its total thickness, a really accurate method of determination is badly needed. The Australasian Expedition hit upon a method which gives positive results, in some cases at least. This consists in taking serial temperatures of the sea-water in depth near the face of the shelf-ice. As there is always a current flowing beneath the ice, the bottom of it is likely to be marked by a sudden slight change in the temperature of the water, easily observed when the observations are plotted as a graph.

## Discussion.

The President (Mr. G. W. Lamplugh) conveyed the thanks of the Society to Sir Douglas Mawson for his luminous description of Antarctic conditions, and for his selection of the magnificent illustrative photographs on this as well as on a former occasion. The fact that the explorer was in this case a thoroughly competent geologist was indeed fortunate. The Fellows had been thus enabled to participate without effort in the new knowledge gained through heroic labour by the lecturer and his comrades. A further privilege was afforded to the Glacial geologists present by Sir Douglas Mawson's readiness to impart the information that he, more than any other man, possessed, and, as time was limited, the President hoped that the speakers would take advantage of this privilege rather than give expression to their particular views.

For his own part, he would like to ask at once whether Sir Douglas had formed any opinion as to the origin of the evidently bold land-features that were buried under the ice—could they have been carved out by the ice itself, or were they the relics of a time when the land was ice-free?

Prof. P. F. Kendall enquired how much wastage of the Antarctic ice was due to melting? This had been an important factor during the disappearance of the British ice-sheets, but was apparently unimportant under present conditions in the Antarctic.

Sir Henry Howorth, after a general statement of the differences between the glacial phenomena in the Arctic and those in the Antarctic, said that it had been formerly believed that the greater part of the Southern Continent was a vast, low-lying, more or less flat surface covered with a dome-shaped ice-cap. This was Croll's view, and an important element in his presentation of the Glacial theory which he insisted upon in a polemic with the speaker. But it was now evident that, instead of being a low plain, this continent is a congeries of high lands partly masked by a mantle of ice and snow, resembling Greenland, whence true glaciers flow radially from a large Mer de Glace probably consisting of embayed ice. Such a land is fundamentally different from a polar ice-cap, as understood by Agassiz and Croll and other inventors and propagators of the Glacial Nightmare. The speaker maintained that ice cannot move unless under the influence of gravity on a slope of sufficient gradient, and if the slope ceases it can only move when pushed by ice coming down the slope behind. Croll's hypothesis needed a huge mound of ice with a sufficient sloping top to enable the layers of ice to move over each other in lieu of the sloping bed; hence his view as to an Antarctic ice-cap. But such a mass could not exist, since the *modulus* or crushing strain under which ice gives way only admits of a very moderate piling-up of an ice-cap. This makes it impossible and not merely improbable that, for instance, the postulated Scandinavian ice-sheet could carry boulders to England and the Carpathians across hundreds of miles of level plains. Sir Douglas Mawson had suggested that the

ice in the central part of the Southern Continent is of portentous depth, but the speaker saw no evidence to support such a postulate. He regretted that the recent expeditions had not been supplied with boring rods to test the depth. There were other geological issues on which the South Polar region throws much light, and the speaker expressed disappointment that time was not allowed for an adequate discussion of them.

Dr. J. W. Evans supplemented Prof. Kendall's question by enquiring whether Sir Douglas Mawson could give any idea of the relative importance of melting, evaporation, and wind action in the removal of material from the surface of the ice-cap.

Mr. G. W. Young asked whether the annual banding, so noticeable in the shelf-ice, was analogous to the 'dirt-bands' of Alpine glaciers (which he thought improbable) or to some physical difference in the ice, the optical appearance of which was accentuated in the photograph.

Mr. A. E. Kitson asked, with regard to the islets in Ross Sea, which show very ragged outlines, whether they have had smoothed surfaces such as are usually found on ice-worn rocks, and owe their ragged character to later subaërial erosion; or have they never been smoothed by ice? If the latter, then there seems to be evidence in favour of the suggestion that, owing to the sliding of the ice-sheet over slippery layers in it, there has not been much wearing away of the land-surface. He also enquired whether anything was known as to the relative thicknesses of the ice-shelf and the glaciers that are forcing their way through it. Is there any probability of ascertaining by boring methods the thickness of the less slowly-moving parts of the ice-sheet on the plateau area nearer the Pole?

Sir Aubrey Strahan remarked that much of the interest of observations made in Polar regions lay in the light which they threw upon the glacial phenomena of our own country. Of these one of the most conspicuous was the great development of boulder-clays and glacial gravels. He had found, in a limited experience, that such deposits were not so well developed in some northern regions where glaciation had been prolonged and intense, as for example in part of Lapland. He had had, however, an opportunity of observing, in company with the President, an instructive example of recently formed boulder-clay. Ice-tongues, protruding from the inland ice, had invaded some of the bays in Spitsbergen, and the material pushed out by them resembled in every respect a typical British till, including fragments of marine shells or boulders. It was clear that the material had been formed under ice which had invaded the sea, and from under which the escape of mud and water was impeded. It would be interesting to know whether boulder-clay was being formed under the ice-tongues, and especially the ice-shelves, in the Antarctic.

He expressed his indebtedness to Sir Douglas Mawson for his exposition. It was given to few to have the hardihood to visit such a region, the skill to return from it, and the ability to give so lucid a description of it.

The PRESIDENT supplemented the questions by asking whether the lecturer could express any opinion as to (1) whether, if the great table of shelf-ice continued to grow by accretion, it would eventually become merged into the main ice-sheet; (2) how much of the remarkable seaward extension of the huge ice-tongues was due to forward flow, and how much to growth-in-place by snow-drift; and (3) what happened when an advancing ice-front over-rode a rocky island well separated from the mainland?

Sir DOUGLAS MAWSON, in replying, said that he would take the President's questions first. As to the origin of the land-features—he did not want to commit himself on this difficult point at present, but was inclined to think that the physiography, so far as one sees it, might all have been produced by ice if no other agency had been available; but it was most likely that the ice started upon a surface already sculptured to some extent. He felt sure, however, that the Antarctic ice could and did cut deep channels, not only above but also below sea-level. Where the ice was thickest it burrowed fastest, and tended, therefore, always to accentuate any existing hollow.

As to the growth of the shelf-ice—although there was a large accretion at the top by snow swept off the land, there was also probably much dissolution below by the action of the sea-water; so that the net increase of the mass was not so rapid as appeared at first sight.

That there was forward movement of the ice-tongues was proved by the way in which they ploughed through the fixed shelf-ice and by their upward bulging where they struck bottom; but most of their movement was over sea-water, and therefore easy and almost frictionless.

Where the ice-sheet abutted upon an island, it depended upon the relative proportions of ice and land whether the land was entirely overridden or the ice-flow split and diverted. Examples of both phenomena were observed.

As to the rate of wastage by melting, the great ice-plateau by causing an outflow of cold air kept the temperature at the ice-margin too low for much melting. What melting there was depended mainly upon the lie of the ice-slope in relation to the sun. There was also a good deal of wastage, both of snow and of ice, by direct evaporation, depending upon the season. But the main wastage was due to the descending winds, which fiercely and almost continuously swept the outer slopes.

With regard to the thickness of the ice, there was perhaps no direct evidence, but a great amount of indirect evidence all indicating that it must in places be very thick—probably several thousands of feet. Boring had been thought of, but would be impracticable because of the movement of the mass at differential rates, so that the borehole could not be kept plumb or open. There were some new instruments, however, invented for marine purposes, which might eventually yield positive information.

The banding of the ice was not due to dirt or dust, which was

practically absent in the Antarctic, but to differences of structure and density, marking the seasons.

The rugged surfaces of the islets are probably due to frost-splintering and marine action, and do not imply that they have suffered no ice-erosion.

The drift deposits are scanty, because there is so little flat land exposed on which they could accumulate. But the sea-bottom carries a great accumulation of clay with boulders for a long distance northwards from the present ice-front.

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November 20th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Walter Clifford Tyndale, O.B.E., M.Inst.C.E., Swallowfield, St. Stephen's Road, West Ealing, W. 13; and Frank McLeod Wasse, Eastcourt, Sidcup (Kent), were elected Fellows of the Society.

The List of Donations to the Library was read.

The names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The President referred with regret to the loss that the Society had sustained by the death of Miss Maude Seymour, on November 6th, 1918, after a very short illness. He alluded to the high value of her services as an Assistant in the Library, and to her energetic assistance in the preparation of the 'List of Geological Literature.'

The following communication was read:—

'The Geology of the Meldon Valleys, near Okehampton, on the Northern Verge of Dartmoor.' By Richard Hansford Worth, M.Inst.C.E., F.G.S.

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December 4th, 1918.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Ralph du Boulay Evans, B.A., H.M. Geological Survey, 28 Jermyn Street, S.W. 1; Reginald Henry Goode, M.A.,

St. John's College, Cambridge; George Gordon-Thomas, Leurie-n-Kans (Northern Nigeria); Walter Stanley Hopkins, Braybrook Road, Wargrave (Berkshire); Capt. Walter Willson Jervis, M.Sc., University College, Exeter; Francis Wilfred Lawfield, B.A., 31 Collier Road, Cambridge; Willet Green Miller, M.A., LL.D., F.R.S.C., Provincial Geologist of Ontario, Toronto (Ontario); Capt. Richard Brian Murray, R.E., Cleveland House, St. James's Square, S.W. 1; Capt. Percy Edward Raine, 2nd D.C.L.I., The Hanburies, Bishop's Frome, Worcester; William Terrey, Snaithing Croft, Sheffield; Thomas Sidney Thomas, 4 Victoria Road, Lydney (Gloucestershire); and David Neville Turner, Calow, Chesterfield, were elected Fellows of the Society.

The List of Donations to the Library was read.

The names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communication was read:—

'The Carboniferous Succession of the Clitheroe Province.' By Lt.-Col. Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S., and Albert Wilmore, D.Sc., F.G.S.

Fossils, photographs, maps, and lantern-slides were exhibited by Lieut.-Col. Wheelton Hind and Dr. A. Wilmore, in illustration of their paper.

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December 18th, 1918.

Mr. G. W. Lamplugh, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'On a Bed of Interglacial Lœss and some Pre-Glacial Freshwater Clays on the Durham Coast.' By Charles Taylor Trechmann, D.Sc., F.G.S.

Proboscidean bones from the Durham Coast were exhibited by Dr. C. W. Andrews, F.R.S., F.G.S., in illustration of Dr. Trechmann's paper.

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January 8th, 1919.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following Fellows of the Society, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—Henry A. Allen and S. Hazzledine Warren.

The following communications were read:—

1. 'On "Wash-outs" in Coal-Seams and the Effects of Contemporary Earthquakes.' By Percy Fry Kendall, M.Sc., F.G.S., Professor of Geology in the University of Leeds.

2. 'On Sandstone Dykes or Rock-Riders in the Cumberland Coalfield.' By Albert Gilligan, D.Sc., F.G.S.

Maps, diagrams, and rock-specimens were exhibited by Prof. P. F. Kendall and Dr. A. Gilligan, in illustration of their respective papers.

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January 22nd, 1919.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Capt. John Ewart Trounce Barbary, R.G.A., Mount Whistle, Camborne (Cornwall); William George Clarke, Secretary of the Prehistoric Society of East Anglia, 12 St. Philip's Road, Norwich; John Alfred Codd. M.D., B.Sc., 7 Tettenhall Road, Wolverhampton; Christopher Charles Fagg, 20 Palace Square, Upper Norwood, S.E. 19; William Thomas Gordon, M.A., D.Sc., F.R.S.E., Geological Department, King's College, London, W.C. 2; Benode Behari Gupta, B.Sc., 17 Westbourne Road, Edgbaston, Birmingham; William McNeill, A.R.S.M., Assoc.M.Inst.C.E., 19 St. Saviour's Road, St. Leonards-on-Sea; Caleb Frank Williams, B.Sc., The Oakfield, Hawarden (North Wales); and Nai Yone, M.Sc., 21 Ashburn Place, London, S.W. 7, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Occurrence of Extensive Deposits of High-Level Sands and Gravels resting upon the Chalk at Little Heath, near Berkhamsted.' By Charles Jesse Gilbert, F.G.S.

2. 'Notes on the Correlation of the Deposits described in Mr. C. J. Gilbert's paper with the High-Level Gravels of the South of England (or the London Basin).' By George Barrow, F.G.S.

Specimens of pebbles, derived fossils, sun-cracked and ripple-marked sandstones, were exhibited by Mr. C. J. Gilbert, in illustration of his paper.

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February 5th, 1919.

Mr. G. W. Lamplugh, F.R.S., President, in the Chair.

Kenneth Wilson Earle, M.Sc., Assistant in the Geological Department of University College, London, 5 Wellesley Mansions, West Kensington, W. 14, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Geology of the Marble Delta (Natal).' By Alexander Logie Du Toit, B.A., D.Sc., F.G.S.

Rock-specimens, photographs, and microphotographs of rock-sections were exhibited on behalf of Dr. A. L. Du Toit, in illustration of his paper.

## *ANNUAL GENERAL MEETING.*

February 21st, 1919.

GEORGE WILLIAM LAMPLUGH, F.R.S., President, in the Chair.

### REPORT OF THE COUNCIL FOR 1918.

DURING the year under review, 32 new Fellows were elected into the Society (the same as in 1917), and 2 Fellows were readmitted. Of the Fellows elected in 1918, 24 paid their Admission Fees before the end of that year, and of the Fellows who had been elected in the previous year, 8 paid their Admission Fees in 1918, making the total accession of new Fellows during the past year amount to 32 (3 more than in 1917).

Allowing for the loss of 65 Fellows (12 resigned, 39 deceased, and 14 removed), it will be seen that there is a decrease of 33 in the number of Fellows (as compared with a decrease of 11 in 1917).

The total number of Fellows is, therefore, at present 1189, made up as follows:—Compounders 213 (13 less than in 1917); Contributing Fellows 962 (27 less than in 1917); and Non-Contributing Fellows 14 (1 less than in 1917).

Turning now to the Lists of Foreign Members and Foreign Correspondents, the Council has to regret the loss during the past year of Dr. G. K. Gilbert and Prof. A. Rothpletz, Foreign Members, and Dr. S. W. Williston and Dr. C. R. Van Hise, Foreign Correspondents. It will be remembered that, in the List of Foreign Members at the end of 1917, there were four vacancies, and eight in that of Foreign Correspondents; and, as no elections were held to make up the numbers during the past year, there are, at present, six vacancies in the List of Foreign Members and ten vacancies in that of Foreign Correspondents.

With regard to the Income and Expenditure of the Society during 1918, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £62 1*s.* 7*d.* brought forward from the previous year) amounted to £2980 13*s.* 9*d.*, being £317 19*s.* 9*d.* more than the estimated Income.

On the other hand, the Expenditure during the same year amounted to £2934 17*s.* 10*d.*, being £222 3*s.* 10*d.* more than the estimated Expenditure, and the year closed with a Balance in hand of £107 17*s.* 6*d.*

As regards the publications of the Society, the Council has to announce the completion of Vol. LXXIII of the Quarterly Journal (1917).

In accordance with the provisions of the modification of Bye-Law Section VI, Art. 4, sanctioned at the Special General Meeting of March 10th, 1915, the Council has, on the motion of the Treasurer, remitted the contributions of 51 Fellows serving with His Majesty's Forces (2 more than in 1917).

During the past year the Apartments of the Society have been used for General and for Council Meetings by the Institution of Mining Engineers, the Institution of Mining & Metallurgy, the Institution of Water Engineers, the Institution of Municipal & County Engineers, the Society of Engineers, the Mineralogical Society, the Palæontographical Society, the Ray Society, the South-Eastern Union of Scientific Societies, the Geological Physics Society, and the Conference of Delegates of Corresponding Societies of the British Association for the Advancement of Science.

Sir Aubrey Strahan and Prof. W. G. Fearnsides have continued to act during the year as our representatives on the Conjoint Board of Scientific Societies.

The Council desires to place on record its high appreciation of the services rendered during the War by the Librarian, Mr. C. P. Chatwin who, despite the increased work devolving upon him in the Library, gave constant help in the general conduct of the Society's business, in the absence of other members of the permanent staff.

The sixteenth Award from the Daniel-Pidgeon Trust Fund was made on March 20th, 1918, to James Arthur Butterfield, M.Sc., who proposed to conduct researches in connexion with the Conglomerates and Sandstones underlying the Carboniferous Limestone Series in the North-West of England.

The following Awards of Medals and Funds have also been made:—

The Wollaston Medal is awarded to Sir Aubrey Strahan, in recognition of his 'researches concerning the Mineral Structure of the Earth,' more especially in connexion with the Stratigraphy, the Geological Cartography, and the Development of the Mineral Resources of Britain.

The Murchison Medal, together with the sum of Ten Guineas from the Murchison Geological Fund, is awarded to Dr. Gertrude L. Elles, in recognition of the value of her contributions to the Stratigraphy of the Older Palæozoic Rocks of Wales, and of her palæontological researches on the Graptolitoidea.

The Lyell Medal, together with the sum of Twenty-five Pounds, is awarded to Dr. William Fraser Hume, as an acknowledgment of the value of his researches on the Upper Cretaceous Rocks of England and Ireland, and of his contributions to the Geology, Physiography, and knowledge of the Natural Resources of Egypt.

The Bigsby Medal is awarded to Sir Douglas Mawson, in recognition of his contributions to our knowledge of Australasia and Antarctica, and as an incentive to further work.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Dr. Alexander Logie Du Toit, as an acknowledgment of his contributions to the Geology and Petrography of South Africa, and in order to stimulate him to further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mrs. Eleanor M. Reid, in recognition of the value of her palæobotanical researches on the Tertiary and Pleistocene Deposits.

A Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. John Pringle, in appreciation of his stratigraphical work on the Palæozoic and Mesozoic Rocks of Great Britain, and in order to encourage him to further work.

A second Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. Stanley Smith, in recognition of the value of his researches on the Stratigraphy of the Carboniferous Rocks of the North of England and of his palæontological studies on the Carboniferous Anthozoa, and in order to stimulate him to further research.

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## Report of the Library Committee for 1918.

The accessions during the year are approximately the same in number as those of the two previous years, but are slightly different in character. The number of complete volumes received is smaller, and that of separate parts and pamphlets larger. Among the pamphlets a series of 594 has been received from the library of the late Dr. G. J. Hinde, F.R.S., through the kindness of Mr. W. Whitaker.

During the year 208 Volumes have been bound, but probably some time will elapse before any more can be done, on account of the scarcity of materials. The state of overcrowding in the top gallery of the Upper Library (referred to in the Annual Report for 1917) still exists, and is therefore a task that must be taken in hand so soon as circumstances permit. For purposes of reference, certain of the Government Departments requiring information have continued to make good use of the Library.

The sudden loss of Miss Seymour has had a serious effect upon the Library work, as is inevitable in the case of a competent Assistant and a small staff. In consequence, no further work has been possible in the passing of No. 20 of the Record of Geological Literature (1913) through the press, as the Librarian's time has been fully occupied in other ways.

The Donations received during the year number 19 Volumes of separately-published Works, 758 Pamphlets, and 10 detached Parts of Works, also 81 Volumes and 184 detached Parts of Serial Publications, 32 Volumes and 74 detached Parts of the publications of Geological Surveys and other public bodies, and 8 Volumes of Weekly Periodicals.

The number of Maps received shows a notable decrease, only 2 sheets of Geological Maps having been received, but 24 topographical sheets were presented by the Geographical Society of Lima (Peru).

The total number of accessions by Donation amounts, therefore, to 132 Volumes, 758 Pamphlets, and 268 detached Parts.

Among the books and pamphlets already enumerated, especial attention may be drawn to the following works:—'Iron-Ore Occurrences in Canada,' vols. i & ii, by E. Lindeman & L. L. Bolton, 1917; L. Cayeux's 'Introduction à l'Etude Pétrographique des Roches Sédimentaires,' text & atlas, 1916; the Memoir on Ordovician & Silurian Fossils from Yun-nan, by Dr. F. R. C. Reed, 1917; Mr. H. Woods's Monograph on the Cretaceous Faunas of the North-Eastern Part of the South Island of New Zealand (N. Z. Geol. Surv. Palæontological Bulletin No. 4, 1917); the second edition of the Geological Survey Special Reports on the Mineral Resources of Great Britain, vol. iii, Gypsum & Anhydrite, Celestine & Strontianite, 1918; the sixth volume of these Special Reports, dealing with Refractory Materials, Ganister & Silica Rock-Sand for Open-Hearth Steel Furnaces, & Dolomite, 1918; H. J. Johnston-Lavis's Bibliography of the Geology & Eruptive Phenomena of the more important Volcanoes of Southern Italy, second edition, by B. M. Stanton, edited by B. B. Woodward, 1918; the Monograph on the Constitution of Coal, by M. C. Stopes & R. V. Wheeler (issued by the Department of Scientific & Industrial Research, 1918); F. L. Stillwell's Memoir on the Metamorphic Rocks of Adélie Land, 1918; H. S. Washington's monograph on the Chemical Analyses of Igneous Rocks published from 1884 to 1913 inclusive, with a Critical Discussion of the Character & Use of Analyses (a Revision & Expansion of Professional Paper No. 14, U.S. Geol. Surv.), 1918; and the Geological Survey Memoir on the Water-Supply of Essex, by W. Whitaker & J. C. Thresh, 1916 (issued 1918).

The Donors during the preceding year included 91 Government Departments and other Public Bodies, 95 Societies and Editors of Periodicals, and 83 Personal Donors.

The Purchases included 31 Volumes and 6 detached Parts of Works, and 17 Volumes and 18 detached Parts of Works published serially. On January 23rd, 1918, the Council apportioned the sum of £40 from the Balance of the Proceeds of the Prestwich Trust Fund for the purchase of works on Economic Geology. On account of the small number of books on this branch of the subject that are being published at the present time, the whole amount has not been expended in the year under review. By the end of the year the sum of £11 2*s*. 6*d*. had been spent on the purchase of 19 volumes; and a special account has been opened for the Balance, which will be drawn on from time to time.

The ordinary Expenditure incurred in connexion with the Library during 1918 was as follows:—

| | £ | *s.* | *d.* |
|---|---|---|---|
| Books and Periodicals | 42 | 10 | 8 |
| Binding | 142 | 17 | 2 |
| Catalogue Cards | 5 | 0 | 0 |
| Total | £190 | 7 | 10 |

Mr. C. Davies Sherborn reports that

'The Card Catalogue has now been edited up to S, and Vol. XV of the Royal Society's Index of Scientific Papers has been cut up, mounted on cards, indexed, and incorporated, thus including many of the papers issued between 1894 and 1900 of the Authors, from A to H. Vol. XVI of the Royal Society's Index (I to M) is now being cut up. As these volumes take about three months to read through and cut up, before indexing can be commenced, the work is tedious.'

In order to facilitate the answering of official enquiries concerned with matters arising from the War, Mr. Sherborn has prepared a card-index to nearly all geological maps (except British), whether issued as sheets or in books. This index has been of the greatest value, and the means of considerable saving of time; and the Society is much indebted to Mr. Sherborn for the great care and trouble that he has taken over the work, and for the amount of time that he has devoted to it.

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The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :—

## I. Government Departments and other Public Bodies.

American Museum of Natural History. New York.
Australia, Government of the Commonwealth of. Melbourne.
Bergens Museum. Bergen.
Birmingham, University of.
British Columbia.—Department of Mines. Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
Bulawayo.—Rhodesian Museum.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Cambridge (Mass.).—Museum of Comparative Zoology in Harvard College.
Canada.—Department of Mines. Ottawa.
——, High Commissioner for. London.
Cape of Good Hope.—South African Museum. Cape Town.
Cardiff.—National Museum of Wales.
Chicago.—' Field ' Columbian Museum.
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Denmark.—Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Great Britain.—British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
Holland.—Rijksopsporing van Delfstoffen. The Hague.
Hull.—Municipal Museum.
Illinois State Geological Survey. Urbana (Ill.).

India.—Department of Mines.
——. Geological Survey. Calcutta.
——. Surveyor-General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Japan.—Earthquake-Investigation Committee. Tokyo.
——. Imperial Geological Survey. Tokyo.
Kansas.—University of. Lawrence.
Kingston (Canada).—Queen's College.
Leeds, University of.
London.—Imperial College of Science & Technology.
——. Imperial Institute.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academía de Ciencias Exactas, Físicas & Naturales.
——. Instituto Geológico de España.
Mexico.—Department of Mines. Mexico City.
——. Instituto Geológico. Mexico City.
New Jersey.—Geological Survey. Trentham (N.J.).
New Zealand.—Department of Mines. Wellington.
——. Geological Survey. Wellington.
Nova Scotia.—Department of Mines. Halifax.
Ohio Geological Survey. Columbus (Ohio).
Ontario.—Bureau of Mines. Toronto.
Paris.—Académie des Sciences.
——. Bureau français du Catalogue International de Littérature scientifique.
——. Commission des 'Annales des Mines.'
Philippine Is.—Department of the Interior; Bureau of Science. Manila.
Pisa, Royal University of.
Portugal.—Commissão dos Trabalhos Geologicos. Lisbon.
Quebec.—Department of Colonization, Mines, & Fisheries.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth.—School of Mines.
Rome.—Reale Accademia dei Lincei.
São Paulo (Brazil).—Serviço Geologico e Mineralogico. São Paulo City.
——. Secretaria da Agricultura, Commercio & Obras Publicas. São Paulo City.
Sendai (Japan).—Tohoku Imperial University.
South Africa, Union of.—Department of Mines. Pretoria.
South Australia, Agent-General for. London.
——. Department of Forestry. Adelaide.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Southern Rhodesia.—Geological Survey. Salisbury.
Stockholm.—Kongliga Svenska Vetenskapsakademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Geological Survey. Hobart.
——. Secretary for Mines. Hobart.
Tokyo.—College of Science (Imperial University).
Turin.—Reale Accademia delle Scienze.
United States.—Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, Royal University of.
Victoria (Australia), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Washington University. St. Louis (Mo.).
Washington (D.C.).—Smithsonian Institution.
——. Geophysical Laboratory.
Washington, State of (U.S.A.).—Geological Survey. Olympic (Wash.).
Western Australia, Agent-General for. London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.

## II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Basel.—Naturforschende Gesellschaft.
Belfast.—Natural History Society.
Bergen.—'Naturen.'
Bristol Naturalists' Society.
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
Cardiff.—South Wales Institute of Engineers.
Cheltenham.—Natural Science Society.
Chicago.—'Journal of Geology.'
Croydon Natural History & Scientific Society.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Edinburgh.—Royal Scottish Geographical Society.
——. Royal Society.
Falmouth.—Royal Cornwall Polytechnic Society.
Geneva.—Société Paléontologique Suisse.
——. Société de Physique & d'Histoire Naturelle.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Hertford.—Hertfordshire Natural History Society.
Ipswich Field-Club.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Géologique Suisse.
——. Société Vaudoise des Sciences Naturelles.
Leeds.—Yorkshire Geological Society.
Lima.—'Revista de Ciencias.'
——. Sociedad Geográfica de Lima.
Lisbon.—Academia das Sciencias de Lisboa. Coimbra.
London.—British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Magazine.'
——. 'The Naturalist.'
——. 'Nature.'
——. Palæontographical Society.
——. Prehistoric Society of East Anglia.
——. 'The Quarry.'
——. Royal Agricultural Society.
——. Royal Astronomical Society.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Engineers.
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.

Manchester Geological & Mining Society.
——. Literary & Philosophical Society.
Melbourne (Victoria).—Australasian Institute of Mining Engineers.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Nancy.—Académie de Stanislas.
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
New Haven (Conn.).—Academy of Arts & Sciences.
——. 'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Northampton.—Northamptonshire Natural History Society.
Ottawa.—Royal Society of Canada.
Paris.—Société Française de Minéralogie.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Plymouth.—Devonshire Association for the Advancement of Science.
Rochester (N.Y.).—Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Toronto.—Canadian Institute.
Washington (D.C.).—Academy of Sciences.
——. Philosophical Society.
Wellington (N.Z.).—'Journal of Science & Technology.'
——. New Zealand Institute.
Worcester.—Worcestershire Naturalists' Club.
York.—Yorkshire Philosophical Society.

## III. Personal Donors.

Adams, F. D.
Atkinson, W. J.

Baker, H. A.
Boswell, P. G. H.
Brooks, C. E. P.

Carus-Wilson, C.
Cayeux, L.
Chapman, F.
Chilton, C.
Clapp, F. G.
Clifford of Chudleigh, Lord.
Cole, G. A. J.
Cullis, C. G.

Daly, R. A.
Davis, W. M.
Dean, B.
Dewey, H.
Draper, D.
Du Toit, A. L.

Elsden, J. V.

Favre, G.
Fearnsides, W. G.
Fourtau, R.

Goodchild, W. H.
Guébhard, A.

Harmer, F. W.
Hatch, F. H.
Haughton, S. H.
Hawkins, H. L.

Issel, A.

Jackson, J. W.
Jamieson, A. W.
Jones, W. R.

Kitson, A. E.
Knight, C. W.

Lacroix, A.
Lambe, L. M.
Leach, A. L.
Longstaff, Mrs. Jane.
Lugeon, M.

Maitland, A. G.
Marriott, R. A.
Merrill, G. P.
Merwin, H. E.
Miller, W. G.
Mills, T. L.
Montgomery, A.

Negri, G.
Newton, R. B.

Odling, M.

Park, J.
Parkinson, J.
Parsons, L. M.
Pinfold, E. S.
Preller, C. S. du R.

Rastall, R. H.
Reid, Mrs. Eleanor.
Richards, H. C.
Rogers, A. W.

Scalia, S.
Scharff, R. F.
Schwarz, E. H. L.
Seward, A. C.
Sheppard, T.
Sherlock, R. L.
Sigg, H.
Simoëns, G.
Smith, J.
Speight, R.
Stillwell, F. L.
Stuart-Menteath, P. W.

Taber, S.
Thompson, A. B.
Thomson, J. A.
Tyrrell, J. B.

Washington, H. S.
Whitaker, W.
Windhausen, A.
Withers, T. H.
Woods, H.
Woodward, H.
Wright, F. E.

Zealley, A. E. V.

## Comparative Statement of the Number of the Society at the Close of the Years 1917 and 1918.

| | Dec. 31st, 1917. | | Dec. 31st, 1918. |
|---|---|---|---|
| Compounders | 216 | ......... | 213 |
| Contributing Fellows | 989 | ......... | 962 |
| Non-Contributing Fellows | 15 | ......... | 14 |
| | 1220 | | 1189 |
| Foreign Members | 36 | ......... | 34 |
| Foreign Correspondents | 36 | ......... | 34 |
| | 1292 | | 1257 |

*Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1917 and 1918.*

| | | |
|---|---|---|
| Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1917 | | 1220 |
| *Add* Fellows elected during the former year and paid in 1918 | | 8 |
| *Add* Fellows elected and paid in 1918 | | 24 |
| *Add* Fellows reinstated | | 2 |
| | | 1254 |
| *Deduct* Compounders deceased | 6 | |
| Contributing Fellows deceased | 32 | |
| Contributing Fellows resigned | 12 | |
| Non-Contributing Fellow deceased | 1 | |
| Fellows removed in accordance with Sect. VI, Art. 5, of the Bye-Laws | 14 | |
| | — | 65 |
| | | 1189 |
| Number of Foreign Members and Foreign Correspondents, December 31st, 1917 | 72 | |
| *Deduct* Foreign Members deceased | 2 | |
| *Deduct* Foreign Correspondents deceased | 2 | |
| | 68 | |
| | — | 68 |
| | | 1257 |

## Deceased Fellows.

*Compounders* (6).

Aldridge, E. G. [elected 1866].
Bond, F. [el. 1880].
Hinde, G. J. [el. 1874].
Lindley, Sir William [el. 1887].
Lucas, F. A. [el. 1883].
Wigram, R. [el. 1886].

*Contributing Fellows* (32).

Arber, E. A. N. [elected 1901].
Bates, L. J. [el. 1904].
Bonthrone, B. [el. 1897].
Burrows, J. S. [el. 1888].
Carter, W. L. [el. 1884].
Cockin, G. M. [el. 1904].
Codrington, T. [el. 1859].
Cunnington, C. H. [el. 1912].
Dykes, F. J. B. [el. 1901].
Finlayson, A. M. [el. 1909].
Forrest, Lord [el. 1883].
Foulerton, J. [el. 1875].
Gotto, F. [el. 1884].
Grossmann, K. [el. 1895].
Hewlett, A. [el. 1863].
Howarth, J. H. [el. 1893].
Howley, J. P. [el. 1883].
Jones, C. K. D. [el. 1901].
Knipe, H. R. [el. 1912].
Laing, W. S. [el. 1913].
Lebour, G. A. L. [el. 1870].
Moysey, L. [el. 1907].
Oats, F. [el. 1875].
Parker, W. A. [el. 1905].
Purdue, A. H. [el. 1908].
Simmons, E. W. [el. 1915].
Sutherland, H. H. [el. 1890].
Templer, F. G. [el. 1916].
Thomas, I. [el. 1906].
Walton, A. E. [el. 1894].
Watson, J. [el. 1917].
Williams, H. S. [el. 1883].

*Non-Contributing Fellow* (1).

Phear, Rev. S. G. [elected 1859].

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## Fellows Resigned (12).

Bevan, Rev. J. O.
Cochrane, N. D.
Hardy, F.
Howel, R.
Lewis, A.
Milton, J. D.
Morgan, B.
Penruddocke, E. E.
Platt, S. S.
Studd, V. M.
Turner, H. I. C.
Walcott, R. H.

## Fellows Removed (14).

Abrahams, L. J.
Atkin, A. J. R.
Bury, A.
Chaplin, G. P.
Edmunds, L.
Foster, E. Le N.
Fowler, C. C.
Garratt, C. F.
Herzberg, F.
Kitto, N.
Lockett, W.
Nicholl, J. J.
Samwell, N.
Wylie, J. H.

FOREIGN MEMBERS DECEASED (2).

Gilbert, G. K. [elected 1895].
Rothpletz, A. [el. 1905].

FOREIGN CORRESPONDENTS DECEASED (2).

Van Hise, C. R. [elected 1914].
Williston, S. W. [el. 1902].

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After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to Mr. R. M. Deeley, Dr. Alfred Harker, and Prof. W. J. Sollas, retiring from the office of Vice-President and also from the Council, and to the other retiring Members of the Council: Dr. F. L. Kitchin and Mr. R. H. Rastall.

The PRESIDENT then said:—

I desire to call the attention of the Fellows to a presentation which has been made to the Society since the Report of the Council was prepared. I refer to the excellent portrait in oils of our esteemed Fellow and Past President, Dr. Henry Woodward, F.R.S., which now adorns the wall above you.

In thanking Dr. Woodward for this gift I am sure that it will be your wish to express to him our hope that we may still see him often at our Meetings in person, as well as in effigy.

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After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

# OFFICERS AND COUNCIL.—1919.

*PRESIDENT.*

George William Lamplugh, F.R.S.

*VICE-PRESIDENTS.*

Prof. Sir John Cadman, K.C.M.G., D.Sc., M.Inst.C.E.
Prof. John Edward Marr, M.A., Sc.D., F.R.S.
Richard Dixon Oldham, F.R.S.
Sir Jethro J. Harris Teall, M.A., D.Sc., LL.D., F.R.S.

*SECRETARIES.*

Herbert Henry Thomas, M.A., Sc.D.
Herbert Lapworth, D.Sc., M.Inst.C.E.

*FOREIGN SECRETARY.*

Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.

*TREASURER.*

James Vincent Elsden, D.Sc.

---

*COUNCIL.*

Charles William Andrews, D.Sc., F.R.S.
Francis Arthur Bather, M.A., D.Sc., F.R.S.
Prof. Sir John Cadman, K.C.M.G., D.Sc., M.Inst.C.E.
Arthur Morley Davies, D.Sc., A.R.C.Sc.
James Vincent Elsden, D.Sc.
Prof. Edmund Johnston Garwood, M.A., Sc.D., F.R.S.
Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
John Frederick Norman Green, B.A.
Robert Stansfield Herries, M.A.
George Hickling, D.Sc.
John Allen Howe, B.Sc.
Prof. Percy Fry Kendall, M.Sc.
George William Lamplugh, F.R.S.
Herbert Lapworth, D.Sc., M.Inst.C.E.
Col. Henry George Lyons, D.Sc., F.R.S.
Prof. John Edward Marr, M.A., Sc.D., F.R.S.
Richard Dixon Oldham, F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.
Prof. Henry Hurd Swinnerton, D.Sc.
Sir Jethro J. Harris Teall, M.A., D.Sc., LL.D., F.R.S.
Herbert Henry Thomas, M.A., Sc.D.
Samuel Hazzledine Warren.
Prof. William Whitehead Watts, M.A., Sc.D., LL.D., F.R.S.

## LIST OF

# THE FOREIGN MEMBERS

## OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1918.

| Date of Election. | |
|---|---|
| 1884. | Commendatore Prof. Giovanni Capellini, *Bologna.* |
| 1886. | Prof. Gustav Tschermak, *Vienna.* |
| 1891. | Prof. Charles Barrois, *Lille.* |
| 1893. | Prof. Waldemar Christofer Brögger, *Christiania.* |
| 1893. | Prof. Alfred Gabriel Nathorst, *Stockholm.* |
| 1894. | Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*). |
| 1896. | Prof. Albert Heim, *Zürich.* |
| 1897. | Dr. Hans Reusch, *Christiania.* |
| 1898. | Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*). |
| 1899. | Prof. Emanuel Kayser, *Marburg.* |
| 1899. | M. Ernest Van den Broeck, *Brussels.* |
| 1900. | M. Gustave F. Dollfus, *Paris.* |
| 1900. | Prof. Paul von Groth, *Munich.* |
| 1900. | Dr. Sven Leonhard Törnquist, *Lund.* |
| 1901. | M. Alexander Petrovich Karpinsky, *Petrograd.* |
| 1901. | Prof. Antoine François Alfred Lacroix, *Paris.* |
| 1903. | Prof. Albrecht Penck, *Berlin.* |
| 1903. | Prof. Anton Koch, *Budapest.* |
| 1904. | Prof. Joseph Paxson Iddings, *Brinklow, Maryland* (*U.S.A.*). |
| 1904. | Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*). |
| 1905. | Prof. Louis Dollo, *Brussels.* |
| 1907. | Hofrath Dr. Emil Ernst August Tietze, *Vienna.* |
| 1907. | Commendatore Prof. Arturo Issel, *Genoa.* |
| 1908. | Prof. Bundjirô Kôtô, *Tokyo.* |
| 1909. | Prof. Johan H. L. Vogt, *Christiania.* |
| 1911. | Prof. Baron Gerard Jakob de Geer, *Stockholm.* |
| 1911. | M. Emmanuel de Margerie, *Paris.* |
| 1912. | Prof. Marcellin Boule, *Paris.* |
| 1913. | Prof. Johannes Walther, *Halle an der Saale.* |
| 1914. | Prof. Friedrich Johann Becke, *Vienna.* |
| 1914. | Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*). |
| 1914. | Prof. Franz Julius Lœwinson-Lessing, *Petrograd.* |
| 1914. | Prof. Alexis Petrovich Pavlow, *Moscow.* |
| 1914. | Prof. William Berryman Scott, *Princeton* (*New Jersey*). |

# LIST OF

# THE FOREIGN CORRESPONDENTS

## OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1918.

Date of Election.

1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Weimar.*
1894. Dr. Francisco P. Moreno, *La Plata.* (*Deceased.*)
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Berlin.*
1900. Prof. Federico Sacco, *Turin.*
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *East Las Vegas, New Mexico* (*U.S.A.*).
1904. Dr. Henry Stephens Washington, *Washington, D.C.* (*U.S.A.*).
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1906. Dr. Jakob Johannes Sederholm, *Helsingfors.*
1908. Prof. Hans Schardt, *Zürich.*
1909. Dr. Daniel de Cortázar, *Madrid.*
1909. Prof. Maurice Lugeon, *Lausanne.*
1911. Prof. Arvid Gustaf Högbom, *Upsala.*
1911. Prof. Charles Depéret, *Lyons.*
1912. Dr. Frank Wigglesworth Clarke, *Washington, D.C.* (*U.S.A.*).
1912. Dr. Whitman Cross, *Washington, D.C.* (*U.S.A.*).
1912. Baron Ferencz Nopcsa, *Temesmegye* (*Hungary*).
1912. Prof. Karl Diener, *Vienna.*
1912. Prof. Fusakichi Omori, *Tokyo.*
1912. Prof. Ernst Weinschenk, *Munich.*
1913. Dr. Émile Haug, *Paris.*
1913. Dr. Per Johan Holmquist, *Stockholm.*
1914. Dr. Paul Choffat, *Lisbon.* (*Deceased.*)

# AWARDS OF THE WOLLASTON MEDAL

## UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1831. Mr. William Smith.
1835. Dr. Gideon A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. Hugh Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron Leopold von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. The Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. The Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. The Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. William T. Blanford.
1884. Prof. Albert Jean Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Descloizeaux.
1887. Mr. John Whitaker Hulke.
1888. Mr. Henry B. Medlicott.
1889. Prof. Thomas George Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John Wesley Judd.
1892. Baron F. von Richthofen.
1893. Prof. Nevil Story Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Dr. Grove Karl Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.
1903. Prof. Heinrich Rosenbusch.
1904. Prof. Albert Heim.
1905. Sir Jethro J. Harris Teall.
1906. Dr. Henry Woodward.
1907. Prof. William J. Sollas.
1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William B. Scott.
1911. Prof. Waldemar C. Brögger.
1912. Sir Lazarus Fletcher.
1913. The Rev. Osmond Fisher.
1914. Prof. John Edward Marr.
1915. Prof. T. W. Edgeworth David.
1916. Dr. A. P. Karpinsky.
1917. Prof. A. F. A. Lacroix.
1918. Dr. Charles D. Walcott.
1919. Sir Aubrey Strahan.

# AWARDS

OF THE

## BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. Gideon A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape of Good Hope fossils. / M. Alcide d'Orbigny.
1849. Mr. William Lonsdale.
1850. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. Samuel P. Woodward.
1855. { Dr. G. Sandberger. / Dr. F. Sandberger.
1856. Prof. G. P. Deshayes.
1857. Dr. Samuel P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. / Mr. W. K. Parker.
1861. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Dr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John Wesley Judd.
1874. Dr. Henri Nyst.
1875. Prof. Louis C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. Robert Etheridge, jun.
1878. Prof. William J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay H. Traquair.
1882. Dr. George Jennings Hinde.
1883. Prof. John Milne.
1884. Mr. Edwin Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Dr. Benjamin Neeve Peach.
1888. Dr. John Horne.
1889. Dr. A. Smith Woodward.
1890. Mr. William A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville Adelbert Derby.
1893. Mr. John George Goodchild.
1894. Sir Aubrey Strahan.
1895. Prof. William W. Watts.
1896. Dr. Alfred Harker.
1897. Dr. Francis Arthur Bather.
1898. Prof. Edmund J. Garwood.
1899. Prof. John B. Harrison.
1900. Dr. George Thurland Prior.
1901. Dr. Arthur Walton Rowe.
1902. Mr. Leonard James Spencer.
1903. Mr. L. L. Belinfante.
1904. Miss Ethel M. R. Wood.
1905. Dr. Henry Howe Bemrose.
1906. Dr. Finlay Lorimer Kitchin.
1907. Dr. Arthur Vaughan.
1908. Dr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.
1914. Mr. R. Bullen Newton.
1915. Mr. Charles Bertie Wedd.
1916. Mr. William Bourke Wright.
1917. Prof. Percy G. H. Boswell.
1918. Mr. Albert Ernest Kitson.
1919. Dr. A. L. Du Toit.

# AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

## 'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

## SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. The Rev. W. B. Clarke.
1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brögger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Dr. Benjamin Neeve Peach. Dr. John Horne.
1900. Baron A. E. Nordenskiöld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.
1905. Mr. Edward John Dunn.
1906. Dr. Charles T. Clough.
1907. Dr. Alfred Harker.
1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur P. Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.
1915. Prof. William W. Watts.
1916. Dr. Robert Kidston.
1917. Dr. George F. Matthew.
1918. Mr. Joseph Burr Tyrrell.
1919. Miss Gertrude L. Elles.

# AWARDS

## OF THE

## BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. { Mr. Alfred Bell. / Prof. Ralph Tate.
1875. Prof. H. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Dr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith John Williams.
1894. Mr. George Barrow.
1895. Prof. Albert Charles Seward.
1896. Mr. Philip Lake.
1897. Mr. Sydney S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Sir Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.
1905. Prof. Herbert L. Bowman.
1906. Dr. Herbert Lapworth.
1907. Dr. Felix Oswald.
1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.
1913. Mr. Ernest E. L. Dixon.
1914. Mr. Frederick Nairn Haward.
1915. Mr. David Cledlyn Evans.
1916. Mr. George Walter Tyrrell.
1917. Dr. William Mackie.
1918. Mr. Thomas Crook.
1919. Mrs. Eleanor M. Reid.

# AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

## 'LYELL GEOLOGICAL FUND,

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Sir William Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. A. Smith Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Prof. John Edward Marr.
1901. Dr. Ramsay H. Traquair.
1902. { Prof. Anton Fritsch. / Mr. Richard Lydekker. }
1903. Mr. Frederick W. Rudler.
1904. Prof. Alfred G. Nathorst.
1905. Dr. Hans Reusch.
1906. Prof. Frank Dawson Adams.
1907. Dr. Joseph F. Whiteaves.
1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather. / Dr. Arthur Walton Rowe. }
1912. Mr. Philip Lake.
1913. Mr. Sydney S. Buckman.
1914. Mr. C. S. Middlemiss.
1915. Prof. Edmund J. Garwood.
1916. Dr. Charles W. Andrews.
1917. Dr. Wheelton Hind.
1918. Mr. Henry Woods.
1919. Dr. William Fraser Hume.

# AWARDS

OF THE

## BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Edmond Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. Prof. Louis Dollo.
1890. Mr. C. Davies Sherborn.
1891. Dr. C. I. Forsyth-Major.
1891. Mr. George W. Lamplugh.
1892. Prof. John Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Prof. Percy Fry Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William Fraser Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John William Evans.
1901. Mr. Alexander McHenry.
1902. Dr. Wheelton Hind.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.
1905. Dr. E. A. Newell Arber.
1905. Dr. Walcot Gibson.
1906. Prof. W. G. Fearnsides.
1906. Mr. Richard H. Solly.
1907. Mr. T. Crosbee Cantrill.
1907. Mr. Thomas Sheppard.
1908. Prof. T. Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Dr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Prof. Charles Gilbert Cullis.
1912. Dr. Arthur R. Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.
1914. The Rev. Walter Howchin.
1914. Mr. John Postlethwaite.
1915. Mr. John Parkinson.
1915. Dr. Lewis Moysey.
1916. Mr. Martin A. C. Hinton.
1916. Mr. Alfred S. Kennard.
1917. Prof. A. Hubert Cox.
1917. Mr. Tressilian C. Nicholas.
1918. Mr. Vincent Charles Illing.
1918. Mr. William Kingdon Spencer.
1919. Mr. John Pringle.
1919. Dr. Stanley Smith.

## AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel Charles Marsh.
1879. Prof. Edward Drinker Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Sir Jethro J. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William J. Sollas.
1895. Dr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.
1907. Dr. Arthur W. Rogers.
1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.
1915. Dr. Henry Hubert Hayden.
1917. Mr. Robert G. Carruthers.
1919. Sir Douglas Mawson.

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## AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.
1906. Mr. William Whitaker.
1909. Lady (John) Evans.
1912. Library extension.
1915. Prof. Émile Cartailhac.
1918. Sir William Boyd Dawkins.

# AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

### ESTABLISHED UNDER THE WILL OF THE LATE

### Dr. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of microscope.
1881. Purchase of microscope-lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Scientific instruments for Capt. E. F. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Dr. Theodore T. Groom.
1902. Mr. William M. Hutchings.
1904. Mr. H. J. Ll. Beadnell.
1906. Mr. Henry C. Beasley.
1908. Contribution to the Fund for the Preservation of the 'Grey Wether' sarsens on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. Mr. Bernard Smith. Mr. John Brooke Scrivenor.
1915. Mr. Joseph G. Hamling.
1917. Mr. Henry Dewey.

# AWARDS OF THE PROCEEDS OF THE 'DANIEL PIDGEON FUND,'

### FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

### DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1903. Prof. E. W. Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.
1906. Miss Helen Drew.
1907. Miss Ida L. Slater.
1908. Dr. James A. Douglas.
1909. Dr. Alexander M. Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian C. Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.
1914. Prof. Percy G. H. Boswell.
1915. Mr. E. Talbot Paris.
1916. Dr. John K. Charlesworth.
1917. Dr. Arthur Holmes.
1918. Mr. James A. Butterfield.

*Estimates for*

## INCOME EXPECTED.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Compositions | 105 | 0 | 0 | | | |
| Arrears of Admission-Fees | 56 | 14 | 0 | | | |
| Admission-Fees, 1919 | 157 | 10 | 0 | | | |
| | | | | 319 | 4 | 0 |
| Arrears of Annual Contributions | 255 | 0 | 0 | | | |
| Annual Contributions, 1919 | 1690 | 0 | 0 | | | |
| Annual Contributions in advance | 35 | 0 | 0 | | | |
| | | | | 1980 | 0 | 0 |
| Sale of the Quarterly Journal, including Longmans' Account | | | | 161 | 15 | 0 |
| Sale of other Publications | | | | 5 | 0 | 0 |
| Miscellaneous Receipts | | | | 15 | 0 | 0 |
| Interest on Deposit-Account | | | | 11 | 0 | 0 |
| Dividends on £2500 India 3 per cent. Stock | 75 | 0 | 0 | | | |
| Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock | 15 | 0 | 0 | | | |
| Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock | 90 | 0 | 0 | | | |
| Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock | 112 | 0 | 0 | | | |
| Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock | 51 | 16 | 0 | | | |
| Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock | 8 | 0 | 0 | | | |
| Dividends on £500 5 per cent. War Loan 1929–1947 | 25 | 0 | 0 | | | |
| | | | | 376 | 16 | 0 |
| | | | | £2868 | 15 | 0 |

*the Year 1919.*

## EXPENDITURE ESTIMATED.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| **House-Expenditure:** | | | | | | |
| Taxes | | 15 | 0 | | | |
| Fire-Insurance | 20 | 0 | 0 | | | |
| Electric Lighting and Maintenance | 50 | 0 | 0 | | | |
| Gas | 15 | 0 | 0 | | | |
| Fuel | 40 | 0 | 0 | | | |
| Furniture and Repairs | 15 | 0 | 0 | | | |
| House-Repairs and Maintenance | 10 | 0 | 0 | | | |
| Annual Cleaning | 15 | 0 | 0 | | | |
| Washing and Sundry Expenses | 40 | 0 | 0 | | | |
| Tea at Meetings | 20 | 0 | 0 | | | |
| | | | | 225 | 15 | 0 |
| Salaries and Wages, etc. | | | | 1300 | 0 | 0 |
| **Office-Expenditure:** | | | | | | |
| Stationery | 20 | 0 | 0 | | | |
| Miscellaneous Printing | 45 | 0 | 0 | | | |
| Postages and Sundry Expenses | 70 | 0 | 0 | | | |
| | | | | 135 | 0 | 0 |
| Grant to Conjoint Board of Scientific Societies | | | | 20 | 0 | 0 |
| Library (Books and Binding) | | | | 100 | 0 | 0 |
| **Library Catalogue:** | | | | | | |
| Cards | 10 | 0 | 0 | | | |
| Compilation | 50 | 0 | 0 | | | |
| | | | | 60 | 0 | 0 |
| **Publications:** | | | | | | |
| Quarterly Journal, including Commission on Sale | 650 | 0 | 0 | | | |
| Postage on Journal, Addressing, etc. | 80 | 0 | 0 | | | |
| Abstracts of Proceedings, including Postage | 108 | 0 | 0 | | | |
| Record of Geological Literature | 150 | 0 | 0 | | | |
| List of Fellows | 40 | 0 | 0 | | | |
| | | | | 1028 | 0 | 0 |
| | | | | £2868 | 15 | 0 |

JAMES VINCENT ELSDEN, *Treasurer.*

*January 29th, 1919.*

*Income and Expenditure during the*

RECEIPTS.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| To Balance in the hands of the Bankers at January 1st, 1918 | 45 | 0 | 3 | | | |
| ,, Balance in the hands of the Clerk at January 1st, 1918 | 17 | 1 | 4 | | | |
| | | | | 62 | 1 | 7 |
| ,, Compositions | | | | 137 | 2 | 0 |
| ,, Admission-Fees: | | | | | | |
| Arrears | 50 | 8 | 0 | | | |
| Current | 151 | 4 | 0 | | | |
| | | | | 201 | 12 | 0 |
| ,, Arrears of Annual Contributions | | | | 228 | 9 | 6 |
| ,, Annual Contributions for 1918:— | | | | | | |
| Resident Fellows | 1645 | 17 | 6 | | | |
| ,, Annual Contributions in advance | 33 | 12 | 0 | | | |
| | | | | 1679 | 9 | 6 |
| ,, Publications: | | | | | | |
| Sale of Quarterly Journal: * | | | | | | |
| ,, Vols. i to lxxii (less Commission £7 7*s.* 11*d.*) | 110 | 1 | 9 | | | |
| ,, Vol. lxxiii (less Commission £2 18*s.* 7*d.*) | 57 | 8 | 3 | | | |
| | | | | 167 | 10 | 0 |
| ,, Other Publications (less Commission) | | | | 4 | 4 | 6 |
| ,, Refund by Dr. C. T. Trechmann of part of the Cost of Quarterly Journal No. 291 | | | | 96 | 9 | 6 |
| ,, Miscellaneous Receipts | | | | 14 | 19 | 1 |
| ,, Interest on Deposit | | | | 11 | 6 | 6 |
| ,, Grant from the Prestwich Trust Fund, for the Purchase of Books | | | | 40 | 0 | 0 |
| ,, Dividends (less Income-Tax):— | | | | | | |
| £2500 India 3 per cent. Stock | 75 | 0 | 0 | | | |
| £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock | 11 | 1 | 3 | | | |
| £2250 London & North-Western Railway 4 per cent. Preference Stock | 66 | 7 | 6 | | | |
| £2800 London & South-Western Railway 4 per cent. Preference Stock | 82 | 12 | 0 | | | |
| £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock | 37 | 17 | 7 | | | |
| £267 6*s.* 7*d.* Natal 3 per cent. Stock | 5 | 16 | 4 | | | |
| £500 5 per cent. War Loan 1929–1947 | 25 | 0 | 0 | | | |
| | | | | 303 | 14 | 8 |
| ,, Income-Tax recovered | | | | 78 | 11 | 6 |
| | | | | £3025 | 10 | 4 |

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales, etc.... £54 9 3

PAYMENTS.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| By House-Expenditure: | | | | | | |
| Taxes | | 15 | 0 | | | |
| Fire- and other Insurance | 26 | 6 | 0 | | | |
| Electric Lighting and Maintenance | 47 | 13 | 2 | | | |
| Gas | 17 | 9 | 11 | | | |
| Fuel | 30 | 9 | 5 | | | |
| Furniture and Repairs | 13 | 7 | 4 | | | |
| House-Repairs and Maintenance | 5 | 13 | 6 | | | |
| Annual Cleaning | 7 | 15 | 0 | | | |
| Washing and Sundry Expenses | 46 | 16 | 11 | | | |
| Tea at Meetings | 18 | 11 | 9 | | | |
| | | | | 214 | 18 | 0 |
| ,, Salaries and Wages, etc.: | | | | | | |
| Permanent Secretary | 360 | 0 | 0 | | | |
| ,, half Premium Life-Insurance | 10 | 15 | 0 | | | |
| Librarian | 200 | 0 | 0 | | | |
| Library Assistant | 76 | 0 | 0 | | | |
| Clerk | 103 | 0 | 0 | | | |
| Deputy Clerk | 130 | 0 | 0 | | | |
| Junior Assistant | 54 | 12 | 0 | | | |
| House-Porter and Wife | 90 | 2 | 6 | | | |
| Housemaid | 53 | 0 | 6 | | | |
| Charwoman and Occasional Assistance | 23 | 17 | 0 | | | |
| Accountants' Fee | 10 | 10 | 0 | | | |
| Extra Assistance | 8 | 0 | 0 | | | |
| War Bonuses | 79 | 13 | 3 | | | |
| | | | | 1199 | 10 | 3 |
| ,, Office-Expenditure: | | | | | | |
| Stationery | 25 | 19 | 6 | | | |
| Miscellaneous Printing | 50 | 10 | 10 | | | |
| Postages and Sundry Expenses | 76 | 9 | 7 | | | |
| | | | | 152 | 19 | 11 |
| ,, Expenditure on account of Grant from Prestwich Fund | | | | 11 | 0 | 6 |
| ,, Library (Books and Binding, etc.) | | | | 187 | 1 | 0 |
| ,, Library-Catalogue: | | | | | | |
| Cards | 5 | 0 | 0 | | | |
| Compilation | 50 | 0 | 0 | | | |
| | | | | 55 | 0 | 0 |
| ,, Medals (engraving inscriptions) | | | | 1 | 1 | 0 |
| ,, Grant to Conjoint Board of Scientific Societies | | | | 20 | 0 | 0 |
| ,, Publications: | | | | | | |
| Quarterly Journal, Vol. lxxiii, Paper, Printing, and Illustrations | 859 | 19 | 11 | | | |
| Postage on Journal, Addressing, etc. | 78 | 18 | 0 | | | |
| Abstracts, including Postage | 126 | 14 | 3 | | | |
| | | | | 1065 | 12 | 2 |
| ,, Refund of Subscriptions remitted in 1917 (repayment in 1918) | | | | 10 | 10 | 0 |
| ,, Balance in the hands of the Bankers at December 31st, 1918 (includes the amount not expended of the Grant from the Prestwich Fund for the purchase of Books) | 85 | 5 | 8 | | | |
| ,, Balance in the hands of the Clerk at December 31st, 1918 | 22 | 11 | 10 | | | |
| | | | | 107 | 17 | 6 |
| | | | | £3025 | 10 | 4 |

We have compared this statement with the Books and Accounts presented to us, and find them to agree.

HENRY A. ALLEN,<br>S. HAZZLEDINE WARREN, } *Auditors.*

*January 29th, 1919.* JAMES VINCENT ELSDEN, *Treasurer.*

*Statements of Trust-Funds: December 31st, 1918.*

## 'Wollaston Donation Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1918 ...... | 37 | 0 | 2 | By Cost of Medal .................................... | 10 | 10 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock ...... | 32 | 3 | 8 | ,, Award from the Balance of the Fund ............ | 26 | 10 | 2 |
| ,, Income Tax recovered ........................ | 4 | 0 | 5 | ,, Balance at the Bankers' at December 31st, 1918 .... | 36 | 4 | 1 |
| | £73 | 4 | 3 | | £73 | 4 | 3 |

## 'Murchison Geological Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1918 ...... | 29 | 6 | 10 | By Cost of Medal .................................... | | 11 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock ........................ | 29 | 10 | 3 | ,, Award to the Medallist ........................ | 10 | 10 | 0 |
| ,, Income Tax recovered ........................ | 10 | 0 | 2 | ,, Award from the Balance of the Fund ............ | 33 | 5 | 11 |
| | | | | ,, Balance at the Bankers' at December 31st, 1918 .... | 24 | 10 | 4 |
| | £68 | 17 | 3 | | £68 | 17 | 3 |

## 'Lyell Geological Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1918 ...... | 67 | 14 | 2 | By Cost of Medal .................................... | | 15 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan 3½ per cent. Stock ...... | 70 | 7 | 0 | ,, Award to the Medallist ........................ | 25 | 0 | 0 |
| ,, Income Tax recovered ........................ | 8 | 15 | 10 | ,, Award from the Balance of the Fund ............ | 59 | 10 | 11 |
| | | | | ,, Balance at the Bankers' at December 31st, 1918 .... | 61 | 11 | 1 |
| | £146 | 17 | 0 | | £146 | 17 | 0 |

| Receipts | £ | s. | d. | Payments | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1918........ | 10 | 5 | 11 | By Balance at the Bankers' at December 31st, 1918 .... | 24 | 3 | 3 |
| ,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock .................... | 10 | 7 | 2 | | | | |
| ,, Income Tax recovered.................... | 3 | 10 | 2 | | | | |
| | £24 | 3 | 3 | | £24 | 3 | 3 |

## 'Bigsby Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1918........ | 4 | 17 | 8 | By Balance at the Bankers' at December 31st, 1918 .... | 11 | 0 | 6 |
| ,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock ................ | 4 | 11 | 4 | | | | |
| ,, Income Tax recovered .................. | 1 | 11 | 6 | | | | |
| | £11 | 0 | 6 | | £11 | 0 | 6 |

## 'Geological Relief Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1918........ | 36 | 18 | 2 | By Grants .................................... | 12 | 12 | 0 |
| ,, Grant from Prestwich Trust Fund ................ | 48 | 10 | 10 | ,, Balance at the Bankers' at December 31st, 1918 .... | 77 | 10 | 8 |
| ,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock............. | 4 | 3 | 4 | | | | |
| ,, Income Tax recovered .................. | | 10 | 4 | | | | |
| | £90 | 2 | 8 | | £90 | 2 | 8 |

## 'Prestwich Trust Fund.' Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers' at January 1st, 1918........ | 103 | 5 | 10 | By Grant to Geological Society for Purchase of Books . | 40 | 0 | 0 |
| ,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock .................... | 21 | 0 | 0 | ,, ,, Geological Relief Fund .............. | 48 | 10 | 10 |
| ,, Income Tax recovered .................... | 2 | 12 | 6 | ,, Cost of Medal.................................. | 20 | 0 | 0 |
| ,, Interest on Deposit.......................... | | 6 | 0 | ,, Balance at the Bankers' at December 31st, 1918: Current Account .......................... | 18 | 13 | 6 |
| | £127 | 4 | 4 | | £127 | 4 | 4 |

## ‘Daniel Pidgeon Fund.’ Trust Account.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| To Balance at the Bankers’ at January 1st, 1918 | 23 | 13 | 10 | By Award | 38 | 19 | 6 |
| ,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock | 30 | 11 | 4 | ,, Balance at the Bankers’ at December 31st, 1918 | 19 | 2 | 1 |
| ,, Income Tax recovered | 3 | 16 | 5 | | | | |
| | £58 | 1 | 7 | | £58 | 1 | 7 |

# SPECIAL FUNDS.

## Hudleston Bequest.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|---|---|---|
| To Balance at the Bankers’ at January 1st, 1918 | 108 | 18 | 0 | By Balance at the Bankers’ at December 31st, 1918: | | | | | | |
| ,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock | 29 | 0 | 0 | Current Account | 50 | 15 | 6 | | | |
| ,, Income Tax recovered | 10 | 0 | 0 | On Deposit | 100 | 0 | 0 | | | |
| ,, Interest on Deposit | 2 | 17 | 6 | | | | | 150 | 15 | 6 |
| | £150 | 15 | 6 | | | | | £150 | 15 | 6 |

## Sorby Bequest.

| Receipts. | £ | s. | d. | Payments. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|---|---|---|
| To Balance at the Bankers’ at January 1st, 1918 | 108 | 18 | 0 | By Balance at the Bankers’ at December 31st, 1918: | | | | | | |
| ,, Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock | 29 | 0 | 0 | Current Account | 50 | 15 | 6 | | | |
| ,, Income Tax recovered | 10 | 0 | 0 | On Deposit | 100 | 0 | 0 | | | |
| ,, Interest on Deposit | 2 | 17 | 6 | | | | | 150 | 15 | 6 |
| | £150 | 15 | 6 | | | | | £150 | 15 | 6 |

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

JAMES VINCENT ELSDEN, *Treasurer.*

HENRY A. ALLEN, } *Auditors*

## *Statement relating to the Society's Property.*

*December 31st, 1918.*

| | £ s. d. | £ s. d. |
|---|---|---|
| Balance in the Bankers' hands, December 31st, 1918 (includes £29 19*s*. 6*d*. not expended of the Grant from the Prestwich Fund) ........... | 85 5 8 | |
| Balance in the Clerk's hands, December 31st, 1918 | 22 11 10 | |
| | | 107 17 6 |
| Due from Messrs. Longmans & Co., on account of the Quarterly Journal, Vol. LXXIII, etc. .. | 54 9 3 | |
| Arrears of Admission-Fees .................... | 56 14 0 | |
| Arrears of Annual Contributions .............. (Estimated to produce £255 0*s*. 0*d*.) | 432 14 0 | |
| | | 543 17 3 |
| | | £651 14 9 |
| Funded Property, at cost price:— | | |
| £2500 India 3 per cent. Stock ............ | 2623 19 0 | |
| £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock .............................. | 502 15 3 | |
| £2250 London & North-Western Railway 4 per cent. Preference Stock ............ | 2898 10 6 | |
| £2800 London & South-Western Railway 4 per cent. Preference Stock ............ | 3607 7 6 | |
| £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock ................ | 1850 19 6 | |
| £267 6*s*. 7*d*. Natal 3 per cent. Stock ...... | 250 0 0 | |
| £2000 Canada $3\frac{1}{2}$ per cent. Stock .......... | 1982 11 0 | |
| £500 5 per cent. War Loan (1929–1947) .. | 475 0 0 | |
| | | £14191 2 9 |

[Note.—*The above amount does not include the value of the Library, Furniture, and stock of unsold Publications. The value of the Funded Property of the Society, at the prices ruling at the close of business on December 31st, 1918, amounted to* £8762 14*s*. 5*d*.]

JAMES VINCENT ELSDEN, *Treasurer.*

*January 29th, 1919.*

## Award of the Wollaston Medal.

In presenting the Wollaston Medal to Sir Aubrey Strahan, K.B.E., F.R.S., Director of H.M. Geological Survey, the President addressed him as follows:—

Sir Aubrey Strahan,—

The Wollaston Medal has been awarded to you unanimously by the Council in recognition of the high value of your researches concerning the mineral structure of the Earth, particularly in the domain of British Stratigraphy. To these researches you have devoted the whole energy of your manhood, and the results have been commensurate with the endeavour. In every part of our land that you have investigated—in Cheshire, Flintshire, Lincolnshire, the Isle of Wight, the Isle of Purbeck, the South Wales Coalfield, and elsewhere—your work has been characterized by the accuracy and restraint which this Society has ever striven to maintain as the standard for British Geology. Consciously or unconsciously, you have acted upon the admonition in the passage from the Preface to *Novum Organum* standing as a motto on the title-page of our Journal, for you have fulfilled exactly the clauses which, when translated, read: 'to win victories over Nature as a worker rather than over hostile critics as a disputant; to attain, in fact, to clear and demonstrative knowledge instead of attractive and probable theory.'

The Geological Survey maps, in which so much of your life's work is presented in so small a space, are models of clearness and precision; in the accompanying memoirs you have conveyed your results, often of the widest consequence, with inimitable terseness, and the same qualities are displayed in all your unofficial papers on a wide range of subjects. While alert to the philosophical bearings of your studies, you have kept always in view their practical application for the benefit of mankind, and have most successfully used your knowledge for the common weal, both in Peace and in War.

Not by your individual investigations only, but also by your able guidance of the work of others, as Director of the Geological Survey of Great Britain, you have conspicuously advanced the interests and repute of our science.

To me it is most gratifying that I should happen to be the

medium through whom this Medal is passed to you, for it was my good fortune many years ago to be instructed by you in the methods of the Geological Survey, and our comradeship has never since been broken.

Sir Aubrey Strahan replied in the following words:—

Mr. President,—

The award of this Medal to me by the Council of the Geological Society, and the expression of kindly feeling which has marked your presentation of it, have touched me deeply. It is nearly 44 years since I was elected to the Society, and since, almost simultaneously, I was appointed to the Staff of the Geological Survey. During that time it has been my ambition to carry out my duties in the public service in such manner as best to render them useful to the community. The attainment of precision in geological surveying may be an unattainable ideal, but the attempt to secure it involves an amount of patient labour, of which the map speaks less eloquently than the printed volume. Your appreciatory remarks upon the maps with which I am concerned give me special gratification.

Though of late years my time has been largely taken up with administrative duties, I have endeavoured, when circumstances permitted, to add to that great record of research which is preserved in the publications of this Society. I venture to believe that the cordial co-operation between the Society and the Survey, which has been so pleasing a feature in the past, has been maintained during my tenure of office as Director.

The declaration of War, six months after I was appointed to the post, profoundly affected the operations of our staff, and necessitated concentration upon economic problems which were the direct outcome of hostilities. During this troublous time your assistance was invaluable to me, and you have now added to my debt by the kindness of your words to-day. My time for retiring from the Public Service is approaching; but, whatever my future occupations may be, the award of this Medal and the manner of its bestowal will remain among my most cherished recollections.

## Award of the Murchison Medal.

The President then presented the Murchison Medal to Miss Gertrude L. Elles, D.Sc., addressing her as follows:—

Dr. Gertrude Elles,—

On receiving an Award from the Council some years ago you expressed the hope of being able to do some further work. You have since done much further work, and, in awarding the Murchison Medal to you, the Council desires to acknowledge the importance and sustained efficiency of your efforts in advancing Geological Science.

Your skill as a field-geologist has been proved by your excellent stratigraphical work, done partly in collaboration with your colleagues, Miss Wood and Miss Slater, on the Older Palæozoic rocks of Wales and the Welsh Border, a region presenting a severe test, both physically and mentally, to the endurance of its investigators. The results, embodied in successive papers published in our Journal between 1896 and 1909, have served to clarify our knowledge of the structure and rock-sequence of these difficult tracts, with which the memory of the Founder of this Medal is so closely associated.

Besides rendering this great service in the field, you and your co-worker, Dr. Ethel Wood (Mrs. Shakespear) have earned the gratitude of stratigraphers and palæontologists alike by your patient and exhaustive studies of the Graptolites. In the product of these researches, published by the Palæontographical Society, your combination of geological and biological knowledge has given us a comprehensive Monograph, long desired and of extreme usefulness to all investigators of the Older Palæozoic rocks.

Not only as an investigator, but as a teacher and inspirer of others, your influence has been serviceable in the advancement of our science. We know that your pursuits have been interrupted, like those of most of us, by national duties arising out of the War, but now that the stifling cloud is being dispelled, we shall look expectantly for the results of the further researches which you have undertaken.

In handing you the Medal, allow me personally to congratulate you on your past achievement.

Miss Elles replied in the following words:—

Mr. President,—

I am very deeply sensible of, and not a little awed by, the distinction which the Council of this Society has conferred upon me, in adding my name to that honoured list of medallists associated with the great name of Murchison, and I thank you, Sir, for the generous way in which you have spoken of my work.

I am glad, indeed, that you have associated the name of my lifelong friend and fellow-worker, Mrs. Shakespear, with mine upon this occasion, for no one can appreciate more than I do how much I have owed to her constant companionship and collaboration; but there is another to whom we both would wish to acknowledge the greatness of our debt. We were merely the instruments whereby the Monograph of British Graptolites was published: the inspiration of that work in practically every detail was drawn from the mind and teaching of Prof. Charles Lapworth, and how great that inspiration can be only those who have been privileged to work with him can estimate.

My work, Sir, as you have said, has of necessity been interrupted by the War, and unfortunately neither Armistice nor even Peace will at once restore health and strength to our wounded Soldiers and Sailors: for the present, my duty is still with them. But I sincerely hope that before long I may be free to return to my geological work, encouraged afresh by this recognition from the premier Geological Society of the World.

## Award of the Lyell Medal.

In handing the Lyell Medal, awarded to William Fraser Hume, D.Sc., to Sir Jethro Teall for transmission to the recipient, the President addressed him as follows:—

Sir Jethro Teall,—

Twenty-three years ago the Council recognized the worth and promise of Dr. Hume's early work by an award from the Lyell Geological Fund. It now expresses appreciation of his prolonged devotion to geological research by awarding to him the Lyell Medal, which, by the Founder's instruction, must go to one who

'has deserved well of the science.' That Dr. Hume has indeed 'deserved well' is known to all geologists by his published work; but the full measure of his deserts is revealed only to those who, like you, have become closely acquainted with the influence of his self-sacrificing labours in Egypt.

In continuation of his early work, Dr. Hume, before leaving for the East, contributed to our Journal a careful study of the Cretaceous rocks of the North of Ireland, in which his high quality as an observer, both in field and in laboratory, is manifest. The energy and ability which he has shown under trying conditions in his later sphere of work are disclosed in the publications of the Geological Survey of Egypt, in his contributions to the International Geological Congress, and in his masterly summary of the geological history of Egypt during the Cretaceous and Eocene Periods, communicated to us ten years ago.

As Director of the Egyptian Survey Dr. Hume has rendered great service to the country in the practical application of geological knowledge, for beneficial purposes both civil and military. We are aware of the onerous and exacting nature of his duties; but, in handing this Medal to you for him, I desire that you will acquaint him with our hope that he may be able to send us further contributions from the store of knowledge that he has acquired during his sojourn in the East.

Sir Jethro Teall replied in the following words:—

Mr. President,—

I have much pleasure in receiving this Medal on behalf of my friend Dr. Hume, whose kind assistance so greatly added to the interest of my visits to Egypt, and enabled me to appreciate the importance of the work which he and his able colleagues are doing. The news that it had been awarded to him appears to have reached him at Zeitia, on the coast of the Red Sea, and in a letter from that locality, dated February 2nd, he writes:—

'It is particularly gratifying, when working in outer places, far from the haunts of men, to learn that the Council of the Geological Society has deemed my contributions to our science of sufficient value to deserve the award of the Lyell Medal. The problems connected with the ancient land which I have more especially been called to study grow in complexity and interest every year, and there are still vast areas of which our knowledge is imperfect and scanty. Especially on the borders of the Red Sea tectonic and economic problems present themselves which require careful mapping and detailed investigation for their solution. Encouraged by your approval, it will be my desire to obtain more light on these and kindred questions, and finally to

bring together the results of the last twenty years of work in Egypt and place them on permanent record. I ask the Council of the Society and its President to accept my most hearty thanks for their encouragement, in again associating me with a memorial of the great man whom I desire in so many respects to follow.'

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## Award of the Bigsby Medal.

The President then presented the Bigsby Medal to Major Sir Douglas Mawson, D.Sc., addressing him as follows:—

Sir Douglas Mawson,—

In awarding to you the Bigsby Medal the Council feels that it has secured a recipient who fulfils ideally the unusual conditions of the bequest. Well within the stipulated limit of age, you have given most assured proof that you are 'not too young to have done much,' and your unabated energy and application are evidence that you are 'not too old for further work.'

Your arduous geological researches in the New Hebrides, in the Broken-Hill district and in several other difficult regions in Australia, as well as your systematized study of Australian minerals, are in themselves a weighty achievement; and the measure is more than filled from your indomitable work as a scientific explorer on the Antarctic continent. You have added greatly to our knowledge of the structure and conditions of that forbidding land, and we anticipate still further advantage from the publication of the full results of the Australasian Antarctic Expedition, of which you were the organizer and leader. During that expedition every quality of your mind and body was put severely to the test, and not found wanting. I hand to you this Medal as a token of our grateful regard.

Sir Douglas Mawson replied in the following words:—

Mr. President,—

The honour which the Council has so kindly conferred upon me at your hands is deeply appreciated by me. I am very proud to be associated with those investigators whose names appear as former recipients of the Bigsby Medal.

Any credit that my work deserves must be shared by my old friend and instructor, Col. (Prof.) T. W. E. David, whose presence here I am glad to note on this occasion. The Professor, who has

so ably carried the torch of Geological Science from the Mother Country to far Australia, has ever been a driving force behind my labours, whether conducted in the Tropics or in the Polar Zone.

You have referred to the publication of the scientific results of the Australasian Antarctic Expedition: this is a matter upon which, now that the claims of the War are past, I intend to concentrate; and I look forward with pleasure to my return to scientific work. When the Reports appear, I trust that they will fulfil the expectations voiced in your generous remarks.

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## Award from the Wollaston Donation Fund.

In handing the Balance of the Proceeds of the Wollaston Donation Fund, awarded to Alexander Logie Du Toit, D.Sc., to Dr. Herbert H. Thomas for transmission to the recipient, the President addressed him as follows:—

Dr. Thomas,—

The Wollaston Fund has been awarded to Dr. Du Toit by the Council to mark our appreciation of the value of his additions to our knowledge of the mineral structure of the Earth, particularly by his researches in Cape Colony and other parts of South Africa. The sterling quality and the wide scope of his work during a long series of years are made apparent in his maps and written contributions to the Annual Reports of the Cape Geological Commission and of the Geological Survey of the Union of South Africa, which also incidentally reveal the arduous conditions of the investigation and the keen energy of the investigator. Besides these official reports, Dr. Du Toit has published much original work in the Proceedings and Transactions of the South African scientific societies, in which his many-sided ability as stratigrapher, petrographer, and physiographer is displayed; while his excellent discussion of the conditions of underground water-supply, and other economic problems, shows that his knowledge is practical as well as profound.

This award will serve to assure him that the scientific importance of his work is recognized here, as well as in South Africa.

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## Award from the Murchison Geological Fund.

The President handed the Balance of the Proceeds of the Murchison Geological Fund, awarded to Mrs. Eleanor Mary Reid, B.Sc., to Dr. Herbert Lapworth, for transmission to the recipient, addressing him as follows:—

Dr. Lapworth,—

The Council has awarded to Mrs. Eleanor Reid the Murchison Fund, in appreciation of the service which she has rendered by her prolonged and skilful investigation of Tertiary and Pleistocene plant-remains. That our ever-remembered friend and colleague, Clement Reid, should have been cut off in the midst of his work was a deplorable loss to Geological Science, but it is alleviating to find that his labours are being continued by loving and capable hands. During his lifetime Mrs. Reid participated actively in all his later researches, and mastered the ingenious methods by which so much new knowledge has been acquired. Its value is apparent in numerous papers published at home and abroad, of which she and her late husband were joint authors; among them, that on the Pre-Glacial Flora of Britain, published by the Linnean Society (1908); that on the Lignite of Bovey Tracey, in the Philosophical Transactions of the Royal Society (1910); and several studies of the Tegelen Flora published in Belgium and Holland, including the fine Monograph on the Pliocene Floras of the Dutch-Prussian Border prepared for the Geological Survey of Holland (1915).

This award is in recognition of the work that Mrs. Reid has already done; but the Council hopes that it may also serve as an encouragement to her to continue her researches.

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## Awards from the Lyell Geological Fund.

In presenting a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. John Pringle, the President addressed him in the following words:—

Mr. Pringle,—

For many years you have been steadily doing good work, both in

the course of your official duties on the Geological Survey and in your free time, whereby our science has been 'most materially advanced.' Some of the results have been published under your name, notably the descriptions of several important deep borings; but still more are incorporated and acknowledged in the memoirs and other writings of your colleagues, whom you have aided greatly by the discovery, collection, and identification of fossils and by your acute observations in stratigraphy. The quality of the work that you have already done leads us to anticipate further additions to our knowledge from that which you have now in hand, and from any that you may undertake in the future. The Council has awarded to you a portion of the Lyell Fund, in recognition of the value of your work and to encourage you to advance.

The President then presented the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to Stanley Smith, D.Sc., addressing him as follows:—

Dr. Stanley Smith,—

The energy and ability that you have shown in the prosecution of your stratigraphical and palæontological studies among the Lower Carboniferous rocks have already produced most useful results. Your report 'On the Carboniferous Limestone Formation of the North of England, with special reference to the Coal Resources' is a good example of the adaptation of stratigraphical knowledge to economic requirements; your paper on 'The Faunal Succession of the Upper Bernician' marks an important step in the application of modern palæontological method to these rocks; and the thoroughness and insight of your strictly palæontological work are demonstrated in your contributions to this Society on genera of Carboniferous Anthozoa. The Council has awarded to you a portion of the Lyell Fund, in order to mark our appreciation of the progress that you have won and to stimulate you to further endeavour.

# THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

## George William Lamplugh, F.R.S.

It is now my sad duty to review the incessant toll of Death upon our ranks. In preparing brief records of the service done by those who have finished work during the past year, I have received aid from many friends, including Mr. W. Whitaker, Dr. A. Harker, Dr. A. Smith Woodward, Mr. T. C. Cantrill, Dr. J. S. Flett, Dr. F. L. Kitchin, and Mr. B. Lightfoot.

The War has deprived us during the year of five Fellows; one killed in action in France; one missing—presumed killed—in Gallipoli; two, dead from sickness contracted during service; one, drowned at sea. Their lives were demanded, and given at the urgent call of National duty, and Science is inestimably the poorer for the loss.

Lieut. C. H. Cunnington, a Fellow of six years' standing, was born on June 7th, 1889, educated at the University College Schools and entered University College, London, in 1905, where he distinguished himself as a student of Geology, gaining the University Scholarship in Geology in 1907. He took his degree in 1909, obtaining first-class honours in Geology. In 1910 he was appointed to the staff of H.M. Geological Survey as Geologist, and during the ensuing four years was engaged in the survey of the South Midlands around the borders of the Warwickshire Coal-field, where he did excellent work. His results have been published as yet in abstract only, but will appear more fully when the Geological Survey memoirs on the district are issued. Besides this official work, Cunnington had made much progress in his spare time in an investigation of the faunal sequence in the Carboniferous Limestone of certain parts of South Wales. His field-work was marked by thoroughness and penetration, which always held his vigorous speculative faculty under control. His high qualifications and love of his work would have carried him far in the path of geological research if he had lived. An ardent member of the O. T. C. before the War, he entered the Army soon after the outbreak of hostilities, and was sent in 1915 to Gallipoli on special Military duty. He served afterwards at the Front in France, and

was invalided home. In 1917 he underwent a severe operation, from which he recovered sufficiently to resume his civil duties, but was carried off by a relapse on April 26th, 1918, in his 29th year.

Lieut. Eric Warr Simmons, another promising University College man, was born in 1893, educated at the Whitgift Grammar School, Croydon, and in 1911 entered University College, where he obtained the Morris Prize and the University Scholarship in Geology in 1913. He took his degree in 1914 with first-class honours in Geology, and afterwards acted as Demonstrator in that subject. He went out to Gallipoli in 1915, the year of his election into our Society, and was posted 'missing' after the landing at Suvla Bay on August 11th, 1915.

Leonard J. Bates, a mining engineer, of the 18th R. F. D. Company, was killed in action in France on November 10th, 1918. He had been elected a Fellow in 1904.

Captain Charles Kenelm Digby Jones, also a mining engineer, and a Fellow since 1901, died in Siberia on September 25th, 1918.

The drowning of Dr. Lewis Moysey, Captain R.A.M.C., who went down with the hospital ship 'Glenart Castle,' torpedoed in the Bristol Channel on February 26th, 1918, was a painful shock to us. In any circumstance of War, our sorrow for friends lost is aggravated by a sense of avoidable calamity, but in this case there was the added bitterness that the lives were taken in defiance of humane conventions.

Dr. Moysey was born in 1869, educated at Repton School, and graduated at Caius College, Cambridge. Qualifying in medicine, he was for many years in practice at Nottingham. On the outbreak of War he was called to the National Service, and was allotted regimental work in this country until last year, when he was detailed for duty in the East. He met his doom at the beginning of the voyage.

During his busy years in Nottingham Dr. Moysey's inherent interest in palæontology became centred upon the fossils of the Coal Measures, and whatever time he could spare was spent in searching for them and in preparing them for his cabinet. His general scientific knowledge led him to appreciate accurately the relative importance of the specimens, so that anything rare or

unusual was at once recognized as such, and was brought to the notice of the proper specialist. Consequently Carboniferous palæontology owes much to him, not only by reason of his own contributions to the literature, but also by the material which he made available for other workers. Many rarities were obtained by an ingenious method (described by Moysey in the 'Geological Magazine,' dec. 5, vol. v, 1908, p. 220) by which the refractory nodules containing the fossils were heated, soaked, and then alternately frozen and thawed until they cracked readily. One of his palæontological papers was published in our Quarterly Journal for 1910, and others appeared in the 'Geological Magazine.' He also contributed a comprehensive appendix on the fossils from the Derbyshire & Nottinghamshire Coalfield to the Geological Survey Memoir on the district (1913). He joined our Society in 1907, and in 1915 a portion of the Lyell Fund was awarded to him in recognition of the value of his work. Shortly before his death, he presented the whole of his collection of fossil plants to the Sedgwick Museum, Cambridge, and the animal remains to the Museum of Practical Geology at Jermyn Street, London.

Temperamentally unobtrusive, his amiability and quiet self-abnegation gained for him the affection of all who had the privilege of his personal acquaintance.

From our Foreign List we have lost two Members and two Correspondents, of whom three were citizens of the United States.

By the death of Grove Karl Gilbert American science sustains a heavy loss, and a notable figure disappears from the geological world. Born on May 6th, 1843, at Rochester (N.Y.), Gilbert was educated in the same city. His University studies were classical, but his natural endowments clearly marked him out for a scientific career. His first opportunity came when he was appointed an assistant on Wheeler's Survey of the Territories West of the 100th Meridian, and in 1871–73 he surveyed considerable areas of Nevada, Utah, New Mexico, and Arizona. Later he was attached to the Geographical & Geological Survey of the Rocky-Mountain Region, and in 1875–76 made a study of the Henry Mountains of Utah. His report on this district, issued in 1879, at once gave him an assured reputation; for, in addition to a lucid exposition of the laccolitic type of intrusion as there exemplified, he put forward an analysis of the processes of erosion and land-

sculpture, which represented an important advance at that time, and has been the basis of later developments.

Meanwhile Gilbert had joined the newly-established United States Geological Survey, and was engaged in tracing the evidences of the former extension of the Great Salt Lake. The results of this work were published in part in 1882, and more fully in 1890 in the Monograph on 'Lake Bonneville.' Here he set forth a fascinating history of the Pleistocene climate and hydrography of the Great Basin, and further discussed the subsequent deformation of the old shore-levels as throwing light on the problem of isostatic readjustment in the Earth's crust. From this he passed to other areas of the United States, on each of which he has left his mark. Of especial value are his investigations of the structure of the Great Lakes, the history of the Niagara River, and the recession of the Falls. He made important contributions to the study of glaciation and glacial erosion, especially in connexion with the Harriman Alaska Expedition. Other subjects which engaged his attention are earthquakes and earthquake-prediction, the variation of gravity, and the estimation of geological time.

Gilbert's published works, characterized always by a remarkable breadth of view and clearness of treatment, cover a large part of physical geology. Nor does a list of his actual researches adequately represent his services to geological science. His personal character, his single-minded enthusiasm, and his power of grasping the salient features of a problem reacted powerfully upon others. In particular, the addresses which he delivered from time to time as President of various societies were remarkably suggestive and inspiring, and his influence was by no means confined to his own country.

Gilbert was elected a Foreign Correspondent of this Society in 1889, and a Foreign Member in 1895. He died at Rochester (N.Y.) on May 1st, 1918, approaching his 75th birthday. [A. H.]

Charles Richard Van Hise was born on May 29th, 1857, at Fulton in Wisconsin, and was educated in the State University at Madison, where he graduated in 1879 in metallurgical engineering. The influence of his early training is perhaps to be traced in his later work in a certain element of precision, as well as in his attraction towards important practical questions. The diversion of his interest to geology may have been due to the influence of Prof. R. D. Irving, with whom he collaborated in several works

of research. Van Hise remained connected with the University of Wisconsin throughout his career, being Professor, in succession, of Metallurgy, Mineralogy, and Geology, and since 1904 President of the University. From 1883 he had been attached also to the United States Geological Survey, and he was engaged from time to time in many other scientific activities.

The direction of his original researches was determined naturally by his geographical situation, and the study of the pre-Cambrian region of Lake Superior became his life-work. He produced numerous important memoirs on different districts and formations, and in 1911 a Monograph of the United States Geological Survey, written by Van Hise in collaboration with his colleague Prof. Leith, gave the first complete account of the geology of the Lake Superior region as a whole. A large amount of research of a different though related kind is embodied in the elaborate 'Treatise on Metamorphism' which appeared in 1904.

Van Hise's eminence as a geologist was recognized by honorary degrees from the Universities of Chicago, Yale, and Harvard, and he was elected a Foreign Correspondent of this Society in 1914. The War diverted his energies into a new channel. He took the lead in mobilizing all the resources of his University in the service of the country, and himself laboured assiduously in Food Administration and other emergency work. He died on November 19th, 1918, aged 61. [A. H.]

Prof. SAMUEL WENDELL WILLISTON, who was elected a Foreign Correspondent in 1902, was a distinguished palæontologist who added much to our knowledge of the fossil reptiles of the Cretaceous and Permian formations of North America. Born at Boston on July 10th, 1852, he accompanied his parents when a child to the newly-founded State of Kansas, and after completing his course at the public school he entered the Kansas Agricultural College. There he pursued medical studies, and graduated as Master of Surgery in 1875. He became interested in geology through the teaching of Prof. B. F. Mudge, who was then investigating the Cretaceous formations of Kansas, and he soon attracted the notice of Prof. O. C. Marsh, of Yale, who engaged him as assistant for three seasons in collecting fossil vertebrata in the State. He afterwards accompanied Prof. Marsh to Yale, where he not only continued his palæontological work, but also proceeded with medical studies which resulted in his graduating as M.D. in

1880. So early as 1877 Williston began to publish small papers, but Prof. Marsh discouraged his original researches on fossils, and he turned instead to dipterous insects, on which he became one of the leading authorities in the United States. From 1886 until 1890, Williston was Professor of Anatomy at Yale, but in the latter year he returned to Kansas to become Professor of Geology and Anatomy and Dean of the School of Medicine in the University of Kansas at Lawrence. In 1902 he removed to the newly-instituted chair of Palæontology in the University of Chicago, where he continued active researches until nearly the time of his death, on August 30th, 1918. While at Lawrence, Williston's most important original work was his investigation of the reptiles found in the Chalk of Kansas, and the results were finally summarized in 1898 in a well-illustrated volume of the University Geological Survey of Kansas (vol. iv, Palæontology, pt. 1). He continued the same researches at Chicago, where he published not only valuable papers on Plesiosaurs and Pterodactyls, but also a little semi-popular volume on 'Water Reptiles' (1914). During the last decade, however, he devoted attention chiefly to the Permian Reptiles from Texas and Missouri, describing important collections which he had acquired for the University of Chicago. Besides original papers he prepared a small well-illustrated volume on 'American Permian Vertebrates,' issued by the Chicago University Press in 1912. A complete list of his papers up to date, was printed by J. T. Hathaway at New Haven in 1911. Williston was a lovable friend and inspiring teacher, and left many devoted pupils, of whom some have already made important contributions to Vertebrate Palæontology. [A. S. W.]

August Rothpletz, one of our Foreign Members, whose much-discussed work on the tectonic structures of the Alps rendered his name familiar to a wide circle of geologists, was Professor of Geology & Palæontology in the University of Munich. Born on April 25th, 1853, Rothpletz graduated at Leipzig in 1882, and was engaged for a time in the geological survey of Saxony. In 1884 he became a Privat-Dozent at Munich, was preferred to the post of extraordinary Professor there in 1895, and succeeded to the University Chair in 1904 on the death of Zittel. He was an enthusiastic and inspiring teacher.

Besides his Alpine researches, of which the more important results are contained in his 'Geotektonische Probleme' (1894) and

'Geologische Alpenforschungen' (1900–1908), Rothpletz carried out much good work on a wide range of subjects. He was particularly interested in the Calcareous Algæ, and studied them both in the Alps and in Gothland. He wrote also upon the Trias and Jura of the Dutch East Indies, the marine formations of the Canary Islands, the Norwegian sparagmite, the flora and fauna of the Culm of Saxony, the deformation of Ammonites, and other matters. He visited this country on several occasions to take part in scientific meetings, and his exuberance in debate and genial comradeship in the field will be remembered by many geologists among us, who will have found it difficult ever to think of him as an enemy.

From our Home List, by the death of George Jennings Hinde we are deprived of an old colleague who served often on our Council, an active worker in Science, and an honoured participant in our Meetings.

George Jennings Hinde was born in Norwich in 1839, and was educated at the Grammar School in that city.

His first occupation was farming; but connexion with the Woodward family and lectures by Pengelly and others soon led him to study more than the mere surface of the Earth.

In 1862 he went to the Argentine Republic, where he became a sheep-farmer and remained for some years. After returning to England for a short time he went to North America, and there began geological work on his own account, as well as studying under Nicholson, at Toronto. His first paper, in 1875, was a joint one with Nicholson, 'On the Fossils of the Clinton . . . Formations of Ontario.' After this he wrote on Glacial beds in Canada, but soon turned to the palæontological work that was to be the continuous product of his long life.

He was elected a Fellow of our Society in 1874, and served on the Council for many years, doing much work connected with finance and other business matters, as well as contributing largely to our scientific proceedings. The Wollaston Fund was awarded to him in 1882, for his American work, and in 1897 the Lyell Medal, for his valuable researches, especially on 'Fossil Sponges and other minute bodies preserved in cherts, in various formations,' the President, W. H. Hudleston, adding that he had placed himself 'in the foremost rank amongst those who have devoted themselves to the study of minute fossil organisms.'

He was elected a Fellow of the Royal Society in 1896. His

latest honour was the award of the Bolitho Medal by the Royal Geological Society of Cornwall in 1910, for his papers on the geology and palæontology of that county.

The affairs of the Palæontographical Society took up much of his time, and he served as Treasurer for ten years.

Corals were the first group of fossils that he investigated, and he continued to work on them for many years; but almost at the same time he began to work on the smaller bodies, Annelid-jaws and Conodonts. Later on Crinoids, Foraminifera, and Algæ came in for attention. His chief work, however, was on two groups, Sponges and Radiolaria, starting with the former in his 'Inaugural Dissertation' for the degree of Ph.D. at Munich, 'Fossil Sponge-Spicules from the Upper Chalk,' a single flint from Horstead (in Norfolk) yielding the material for an elaborate essay of eighty pages and five plates.

His continued labour made him our chief authority on fossil sponges, to which result two important works largely contributed, the great Catalogue of Fossil Sponges in the British Museum (1883), and the Monograph on Fossil Sponges published by the Palæontographical Society (1886–1912). Besides these, however, a large number of papers from his pen appeared in our Quarterly Journal and in other periodicals.

Turning to Radiolaria, on which his first paper appeared in 1890, he made that class of minute organisms almost his own private preserve, a host of other papers following, contributed to our own Society and to various other Societies.

In both these cases, Sponges and Radiolaria, Hinde was not content merely to describe the fossils; but he paid much attention (often with other workers) to the character and distribution of the beds in which they were found, as, for instance, in his paper on Beds of Sponge-remains in the Greensands, published in the Philosophical Transactions of the Royal Society in 1886, and in many papers relating to Devon and Cornwall.

Among more general works is the 'Report on the Materials from the Borings at the Funafuti Atoll' (1904), in which the borings and the cores from them are described in detail, as well as the Foraminifera, Corals, Algæ, and other organisms that were found, with tables showing their distribution.

Hinde was a first-rate observer, both in the field and in the study, not prone to draw conclusions without careful consideration, keen in controversy, sharp in analysis; and so his work was thorough.

His great knowledge and experience were always at the disposal of his geologic brethren, who did not hesitate to appeal to him; and this held not only in England, but in all countries.

Besides his more general work, that of the district in which he spent the latter part of his life was not passed over as unimportant. He greatly helped in the work of the Croydon Natural History Society, at the meetings of which he was a frequent attendant, especially at those of the Geological Section, where his advice and opinion were much valued. Several papers on local geology, dealing with the fire-stone, the Chalk, and the gravels, came from his pen; but he could never be induced to accept the office of President, to the great regret of the members.

Having been for many years in intimate connexion with many German geologists, whose scientific work he valued, he was much grieved by the barbarous actions of Germany in the Great War, and this somewhat embittered his later days.

Loss of memory hindered his power for work, and, after a long illness, he died at Croydon on March 18th, 1918, when only six days short of the age of 79.

During his long years of work Hinde was a constant collector, and his specimens were not only well selected, but also carefully labelled: his methods were precise. It is, therefore, a matter of great satisfaction to geologists that by the generosity of his widow his fine collection has, for the most part, been added to the national store, at the Natural History Museum. This collection contains a vast number of fine fossils, from various parts, and of microscopic slides, including very many figured specimens. Thus, therefore, has been established the best possible memorial of him and of his work: one, too, that he would like.

His valuable library has, also through the kindness of Mrs. Hinde, been distributed, to a large extent among scientific and educational institutions, as well as among workers at the science that he loved so well. [W. W.]

Henry Shaler Williams, formerly Professor of Geology and Director of the Museum in the Cornell University, was elected a Fellow in 1883. He was born at Ithaca (N.Y.), on March 6th, 1847, and graduated Ph.D. at Yale in 1868. After some useful preliminary research in biology, he was attracted to Palæontology and Geology, which henceforth were the main pursuits of his life. In 1879 he was made Assistant Professor of Geology & Palæon-

tology at Cornell, and became full Professor there in 1886. Six years later he succeeded Dana as Silliman Professor at Yale, but returned to his former post at Cornell in 1904. He retired on pension under the Carnegie foundation in 1912, and died at Havana (Cuba), on July 31st, 1918, at the age of 71. He devoted himself principally to intensive studies of the Devonian rocks of the Eastern States and their fauna, but always with the view of distilling from them such essential principles as might promise to be of wide application. He published over 90 papers and books, the majority of which bore more or less closely upon stratigraphical questions of classification and synchronism arising from the study of faunal relations. By minute and prolonged examination of numerous typical sections in the Devonian rocks he became convinced that the composition of a fossil fauna changes in passing geographically from one place to another, and that the line of succession in fossil faunas is often not directly vertical in the strata but is deflected laterally, so that the local disappearance of a fauna is no proof of its extinction, and 'not only lithologic but palæontologic facts are local.' His broad philosophical outlook is displayed in his well-known treatise 'Geological Biology: an Introduction to the Geological History of Organisms,' published in 1895. This quality, combined with an extreme patience and thoroughness in research, was the hall-mark of all his work. Possessed as he was with high ideals, the sincerity of his aims was recognized by all who knew him, and will be a lasting influence on his students and colleagues.

By the untimely death of EDWARD ALEXANDER NEWELL ARBER, M.A., Sc.D., in his 48th year, our Science has been deprived of an energetic and accomplished investigator in the field of Palæobotany, whose achievement was already great and was steadily expanding. He was born in London on August 5th, 1870, and, after an ailing boyhood, during which his inherent bent for botany was aroused by a stay in Switzerland, he entered Trinity College, Cambridge, in 1895, where, despite ill-health, he took the two parts of the Natural Sciences Tripos in 1898 and 1899, specializing in Botany and Geology. Immediately afterwards he was appointed University Demonstrator in Palæobotany, and thenceforward devoted himself whole-heartedly to the studies which lasted as long as strength remained. Under his care the collection of fossil plants in the Sedgwick Museum grew rapidly in size and importance,

and his own enthusiastic spirit was communicated to many of his students. From the geological point of view, his chief work was done on the abundant plant-remains of the English Coal Measures, but he found time also to deal with collections from many other quarters—from India, Australia, Tasmania, New Zealand, Rhodesia, South Africa, and Newfoundland. Using the plants as guide-fossils, he appealed to them confidently in problems of stratigraphy and classification, applying this method, in particular, to the coal-fields of Cumberland, South Staffordshire, the Forest of Wyre, the Forest of Dean, and Kent, and to the Culm Measures of Devon and Cornwall. His industry was untiring, as is shown by the amount of work that he published during the seventeen years of his active career. A list of his geological and palæontological writings given in a recent number of the 'Geological Magazine' (dec. 6, vol. v, 1918, pp. 428–31) contains 58 items, exclusive of purely botanical works. He contributed seven papers to our Quarterly Journal, besides some appendices to papers by other authors. The 'Philosophical Transactions' and Proceedings of the Royal Society contain five papers by him; several others were published in the Transactions of the Institution of Mining Engineers; and he was a frequent contributor to the 'Geological Magazine,' and to botanical and other scientific journals. Among his separately published works are a British Museum 'Catalogue of Fossil Plants of the *Glossopteris* Flora' (1905), 'The Natural History of Coal' (Cambridge, 1911: translated into Russian, 1914), 'The Coast Scenery of North Devon' (London, 1911). The value and promise of his work was recognized early by the Council, who in 1905 made an Award to him from the Lyell Fund. He was elected a Fellow of our Society in 1901, and was also a Fellow of the Linnean Society. In 1914 he was made an Honorary Member of the New Zealand Institute, in appreciation of his researches on Australasian plant-fossils. He died on June 14th, 1918, leaving a widow, herself an accomplished botanist, and one daughter.

George Steuart Corstorphine, B.Sc., Ph.D., Principal of the South African School of Mines & Technology, Johannesburg, was born in Edinburgh on November 19th, 1865, and was trained as a teacher at Moray House. For two years he taught in schools in Birkenhead and Edinburgh, and then proceeded to Edinburgh University, where he studied biology and geology, taking the degree of B.Sc. in 1891. He won the Baxter Scholarship in Science

(1892), and subsequently the Falconer Fellowship in Geology & Palæontology, which he held from 1892 to 1895. From 1892 to 1894 he acted as Assistant to Prof. James Geikie, taking charge of the practical classes and demonstrations, and was at the same time Lecturer on Geology in the Heriot-Watt College, Edinburgh. For three years he spent several months each year in Munich, where he attended the lectures of Groth, Zittel, and Weinschenk, and devoted most of his time to petrological investigation. He obtained the degree of Ph.D., submitting as a Thesis his paper 'Ueber die Massengesteine des Südlichen Theiles der Insel Arran, Schottland' (Tschermak's Min. Petr. Mittheil, vol xiv, 1895, p. 663). In 1895 a Professorship of Geology was established in the South African College at Cape Town, and Corstorphine was elected to the chair. He took up the work in 1896, and acted at the same time as Keeper of the Geological Department of the South African Museum. The Geological Survey of Cape Colony was also under his charge, though it was not until 1900 that he obtained the title of Director. He spent six busy years in Cape Town, leaving in 1902 to act as Geologist to the Consolidated Goldfields Company at Johannesburg. About this time he became a prominent member of the South African Geological Society, serving as President in 1906, while from 1904 to 1905 he was one of the Honorary Secretaries. In 1908 he set up in practice as a Consulting Geologist in Johannesburg, and in 1913 he was appointed Principal of the South African School of Mines & Technology. He died on January 25th, 1919.

Corstorphine's only contribution to British geological literature was his first paper on the igneous rocks of Arran. This is marked by careful and scholarly work, though, in the enormous expansion which has taken place in our knowledge of Scottish petrography during the last twenty years, it has not attracted much attention. Among South African geologists he at once took and retained a high place. At Cape Town he had, unfortunately, little time for field-work; but in the Annual Reports of the Geological Survey of Cape Colony he published the results of his investigations principally in the history of geological research and the correlation of the different formations of the Colony and adjacent districts. In this way he laid the foundation of an extensive and critical knowledge of South African geological problems, which bore fruit in the well-known text-book of the Geology of South Africa, written conjointly with Dr. F. H. Hatch, and published in 1905.

A second edition was issued in 1909. After he went to Johannesburg in 1902 he contributed several papers to the South African Geological Society. In 1904 he showed that the 'older granite' was unconformably overlain by the Witwatersrand Series: he claimed also that the Transvaal Coalfield was to be ascribed to the Ecca Series (1904), and in a paper written with Dr. Hatch on the petrography of the Rand Conglomerates, he suggested that the gold had been introduced by percolating waters. Most of his time, however, was probably taken up in recent years by administrative duties and professional work. [J. S. F.]

By the death, in his 90th year, of THOMAS CODRINGTON, M.Inst.C.E., the Society has lost an esteemed member whose Fellowship lasted nearly sixty years, and whose occasional contributions to our Proceedings and Journal cover a period of nearly fifty years. He was elected a Fellow in 1859, a year remarkable in our annals as prolific in long Fellowships. His association with us affords a good illustration of the benefit accruing to our Science from the Fellowship of professional engineers. Born at Wroughton (Wiltshire), on May 31st, 1829, Codrington was educated at the College for Civil Engineers, Putney, and, after serving for some years in subordinate positions, he was appointed in 1874 General Superintendent for County Roads in South Wales, undertaking later the supervision of the main roads in Herefordshire also. In 1882 he became an Engineering Inspector under the Local Government Board, continuing in this service until his retirement in 1895, after which he carried on a consultative practice. He was a leading authority on the planning and upkeep of roads, and on this subject he wrote 'The Maintenance of Macadamized Roads' (1879 & 1892), the article 'Roads' in Encyclopædia Britannica (1885), and 'Roman Roads of Britain' (1903, 1905, 1918). He contributed his first paper to our Society in 1860, on the probable Glacial Origin of some Norwegian Lakes. In 1864 he recorded the discovery of Pleistocene Mammalian remains near Thame; in 1868, described a section in the Isle of Wight; and, in 1870, produced a valuable paper on the Superficial Deposits of South Hampshire and the Isle of Wight. Next, after a lapse of 28 years, he submitted an account of some Submerged Rock-Valleys in South Wales, Devon, & Cornwall (1898), in which he most usefully placed on record information of geological importance gathered during engineering operations, and this was

supplemented by a later paper in 1902. His last contribution, 'Some Notes on the Neighbourhood of the Victoria Falls, Rhodesia' (1909), dealt chiefly with the age of the stone-implements which he had collected during his visit to a son, since dead, who was then Administrator in Northern Rhodesia. Codrington resided for some 50 years in Richmond and Twickenham, where he gave much attention to local affairs, and was held in high respect. He died on October 21st, 1918.

We have lost another of our oldest Fellows, with a standing of nearly sixty years, by the death of SAMUEL GEORGE PHEAR, M.A., D.D., formerly Master of Emmanuel College, Cambridge, who also was elected into the Society in 1859. Born at East Stonham in Suffolk on March 30th, 1829, Phear graduated at Cambridge in 1852 as Fourth Wrangler, and continued to be associated with his College in one capacity or another for over seventy years. He recognized the importance of Natural Science as an essential in education before this opinion was prevalent at Cambridge, and his influence was valuable in advancing the study of science in the University. He was elected Master of Emmanuel in 1871, and resigned in 1895 on account of impaired health. He was Vice-Chancellor of the University in 1874 and 1875. He was unmarried, and the last 23 years of his life were spent in quiet retirement at Cambridge, where he died, in his 90th year, on November 26th, 1918.

JOHN FOULERTON, M.D., another of our senior Fellows, elected in 1875, died on June 29th, 1918, at the age of 90. Though not undertaking research himself, he was keenly interested in geological matters and a personal friend of many geologists. He was an active member of the Geologists' Association, serving as its Honorary Secretary for many years in the 'seventies and 'eighties and in other capacities. He bequeathed his large fortune in trust to the Royal Society for the promotion of research in medicine.

JAMES P. HOWLEY, elected a Fellow in 1883, was born at St. Johns on July 7th, 1847, and spent a long life on the Geological Survey of Newfoundland, entering that service in 1866 as Assistant Geological Surveyor under A. Murray, and succeeding him in 1889 as Director. This position he retained until his death on January 1st, 1918, at the age of 71 years. Howley produced district maps of

several parts of Newfoundland, and in 1907 brought together his knowledge in a geological map of the whole island on the scale of 8 miles to an inch. His contributions to geological literature consist principally of a series of Annual Reports, mostly brief, and some pamphlets on the mineral resources of the island. He was particularly interested in the Coal Measures, and reported on the attempts to find workable coal-seams. He paid much attention also to ethnology, and published in 1914 a book on the culture and remains of the Beothics, the aboriginal inhabitants of the island.

Albert Homer Purdue was born near Yankestown (Indiana), on March 29th, 1861, and passed his studentship at the Indiana State Normal School, Terre Haute. After a few years of scholastic work, he entered the Stanford University, California, where he took the A.B. degree, and carried out some geological field-work in the San Francisco peninsula. In 1896 he was elected Professor of Geology (afterwards of Mining also) in the University of Arkansas, and in 1907 became *ex officio* State Geologist of the Arkansas Survey. In 1912 he took the post of State Geologist of Tennessee, in which he continued until his death, after a short illness, at Nashville (Tennessee), on December 12th, 1917. Quiet and unassuming in manner, he was recognized as an excellent teacher of geology both in the lecture-room and in the field. Among the subjects of his numerous papers and reports (see Bibliography by G. H. Ashley in Bull. Geol. Soc. Amer. vol. xxix, 1918, pp. 60–64) may be mentioned the Glacial Drift of Indiana (1895), the Charlestown Earthquake (1896), Valleys of Solution in North Arkansas (1901), Physiography of Boston Mountain, Arkansas (1901), the Slates of Arkansas (1909), and the Zinc-Deposits of North-Eastern Tennessee (1912). He was a member of several American scientific societies, LL.D. of Arkansas University, and was elected a Fellow of our Society in 1908.

The Right Reverend John Mitchinson, an active Fellow of the Society until his resignation a few years ago owing to advancing age, was born at Durham on September 23rd, 1833, educated at Durham School, gained a scholarship at Pembroke College, Oxford, and passed through his collegiate training with high distinction, both in Classics and in Natural Science, proceeding to the M.A. degree in 1857. He was elected to a Fellowship of his College in 1856 and retained it until 1881, was made Honorary Fellow in 1882, and became Master of Pembroke in 1899. From 1857 he

was engaged in scholastic work until 1873, when he was created Bishop of Barbados and the Windward Islands. Already D.C.L. of Oxford and Durham, he received the diploma of D.D. from the latter University in 1873. Returning to England in 1881, he held for some years the benefice of Sibstone (Leicestershire), and was actively engaged in varied duties in the diocese of Peterborough. A keen student of geology, he gathered together, while in Barbados, a collection of fossils which he subsequently presented to the British Museum, and after his return to England he made a further collection, part of which was given to the Museum at Oxford and the remainder to University College, London. He was a man of broad culture, his interests ranging widely in art as well as in science, including particularly the study of monastic foundations and remains, and a deep appreciation of music. His charm of personality and sympathetic feeling rendered his companionship always delightful, and among geologists he could count many devoted friends. He served on the Council of our Society in 1901–1903, and many terms on the Council of the Palæontographical Society. He died suddenly at Gloucester on September 25th, 1918, at the age of 85.

The eminent Australian explorer and statesman, LORD FORREST (better known as Sir JOHN FORREST), whose Fellowship in the Society began in 1883, was a representative of the close bond which has always existed between geographical and geological studies in their broader aspects, but has tended to become less evident under the growth of specialization in both.

Born in 1847 near Bunbury (Western Australia), Forrest spent his whole life in the service of his State and country. Educated at Perth (W. A.), he entered the Survey Department there in 1865, and in 1869, at the age of 22, made his first plunge into the unknown interior, in search of traces of the lost explorer, Leichardt. The following year he started again, in charge of an exploring party which pushed across the desert around the head of the Great Australian Bight, and succeeded in reaching South Australia. In 1874 he led another expedition by a more northerly route through the heart of Western Australia, and emerged safely in the Lake Eyre country after a hard and dangerous journey of 2000 miles, largely on foot. The scientific importance of these explorations of the desert interior was recognized by the Royal Geographical Society in the award of the Patron's Medal to Forrest in 1876. In 1883

he became Surveyor General, with participation in the legislative affairs of his State, at that time a Crown Colony; and when representative government was granted in 1890, he was chosen to be its first Premier. This position he continued to hold until the federation in 1901, when he took office in the Commonwealth Government as Postmaster General, and during the rest of his career played an outstanding part in the political and administrative life of the Commonwealth. He was a strenuous advocate for the building of the great Transcontinental Railway which now links Western Australia to the Eastern states, and its completion during his lifetime gave him intense gratification. His manifold services to the Commonwealth and Empire brought him many honours: K.C.M.G. in 1891; G.C.M.G. in 1901; P.C.; LL.D. of Cambridge, Perth, and Adelaide; and in 1918 he was created a Baron of the United Kingdom, being the first Australian peer. He died at sea on September 3rd last, at the age of 71, leaving a widow but no children.

Forrest was a big man, physically and mentally; genial and practical. With an air of broad spaces about him, he struck the imagination as a fitting representative of the Island-Continent.

Sir William Heerlein Lindley, eminent as a civil engineer, was elected a Fellow in 1877, and died on December 30th, 1917, at the age of 64. He spent most of his life in professional work on the Continent, principally in Germany and Austria, where he was associated with many great public works for water-supply, drainage, etc. He rendered considerable service to the Royal Commission on Canals & Inland Navigation by preparing an exhaustive report on the waterways of France, Belgium, Germany, and Holland, which was published as a Blue book. In recognition of the value of this work he received the honour of knighthood in 1911.

Ivor Thomas was born on November 24th, 1877, and became a Fellow of this Society in 1906. Commencing his career as a teacher at the Glanamman Council School, he afterwards graduated with honours at Aberystwyth. After a short period devoted to teaching, he proceeded to Germany, where he studied geology and palæontology under Prof. Emanuel Kayser. Thomas returned to this country in 1905, a graduate of Marburg University, and was appointed to the staff of the Geological Survey of Great Britain. There he was attached to the Palæontological Department until

his transfer from the Survey, early in 1912, to the Welsh Inspectorate of Schools. Although it was known that he had latterly suffered a failure in health, his untimely death on March 30th, 1918, came as a shock to his friends and former colleagues.

Thomas's work as a palæontologist was marked, above all, by thoroughness and soundness. His patience and industry enabled him to overcome many difficulties, and to complete laborious researches which involved great attention to details. That this faculty for dealing with minutiæ was combined with broader critical powers is fully demonstrated in his published writings, the most important of which are his well-known studies of Carboniferous brachiopods, issued in 1910 and 1914 by the Geological Survey.

Ivor Thomas was an ardent Welsh nationalist, and was keenly interested in the problems of education within the Principality. The lure of his homeland led him to relinquish a scientific career of great promise, and one in which he had already established himself. His loss is deplored by all who were associated with him in his geological work; more particularly by those former colleagues who, by daily contact with him, could best appreciate his amiability and sincerity of character. [F. L. K.]

Arthur Edmund Victor Zealley, Assoc.R.C.S., was born in Worcestershire on March 1st, 1886. His parents' desire was that he should devote himself to Chemistry, the science followed by his grandfather and uncles on his mother's side. He received his early education at the Royal Grammar School, Worcester, where his natural bent towards Geology exhibited itself in his pleasure in collecting shells and fossils. He proceeded to the Royal College of Science, South Kensington, where he studied under Prof. Watts and obtained his Associateship in Geology. He remained for some time at the School of Mines as a demonstrator and lecturer.

In 1909 he accepted the appointment of Curator & Geologist to the Bulawayo Museum on the retirement of Mr. F. P. Mennell, and in this capacity he did much useful work in determining minerals and reporting on mineral occurrences.

When the Geological Survey of Rhodesia was started under the leadership of Mr. H. B. Maufe, Zealley was the first geologist to be appointed, and he began work in 1911. Among the results of his labours already made known in the publications of the Geological Survey of Southern Rhodesia are reports on the Selukwe, Gatooma, and Umtali Gold-Belts and on the Somabula Gravels, but a con-

siderable amount of his work is still unpublished. He was on the point of leaving for England when he was struck down with influenza which was followed by pneumonia, and he succumbed after an illness of 10 days on October 28th, 1918, aged 32. His wife, a lady of great literary ability, had predeceased him by a few months. By his death we have lost a keen and conscientious worker on the threshold of his career. [B. L.]

George Marmaduke Cockin, long connected with the coal-industry of the Brereton district of South Staffordshire, was born on February 2nd, 1852, at Birmingham where his father was Rector of St. George's. Educated first at King Edward's School in that city and later at Richmond (Yorkshire), he was trained as a mining engineer at Monkwearmouth, and subsequently held several appointments in the county of Durham. He next turned to silver-mining in Mexico and then to farming in Dakota; but, returning to England, he obtained a mining post at Ellistown in Leicestershire, relinquishing it in 1895 on being made mining engineer to the Marquis of Anglesey, an office he held until his death.

He was a Fellow of this Society for 14 years, and in 1906 published in our Journal an important paper in which he proved the previously unsuspected occurrence of Carboniferous Limestone beneath the Coal Measures of the Cannock-Chase district of South Staffordshire. In papers published elsewhere he dealt with the ancient iron-smelting and other industries of Cannock Chase, recorded details of a prehistoric flint-factory, and described the basement-rocks of the Bunter of the same district.

He died suddenly in his office at Rugeley on January 15th, 1918, in the 66th year of his age, and was buried at Brereton.

[T. C. C.]

William Lower Carter, a frequent participant in our meetings of late years, and well known among geologists generally from his long service as Secretary & Recorder to the Geological Section of the British Association, and previously as Hon. Secretary of the Yorkshire Geological Society, was elected a Fellow in 1884. He was born on August 9th, 1855, and received his early education at Derby School, where his bent for Natural Science declared itself. He began independent life as a bank clerk, but on the impulse of a call to the Congregational ministry, he entered upon a course of

qualifying study at Springhill College, Birmingham, and afterwards at Emmanuel College, Cambridge, where he took first-class honours in the Natural Science Tripos, specializing in Geology. After further training at Halle (Germany) and Birmingham, he entered the ministry and held charge successively at Bilston (Staffordshire), Hopton (Mirfield) and Oxton (Birkenhead). Retiring from this sphere of duty in 1908, he accepted the post of Lecturer in Geology at the East London College and, later, lectured also on Geology and kindred subjects at other colleges and institutions in London, continuing this work until struck down by apoplexy while lecturing at Queen's College. He lingered only a few days, and died on June 22nd, 1918. It was as an organizer and administrator more than as an investigator that Carter contributed to the advancement of our science. A genial comrade and experienced guide in the field, his services were even more valuable in the study, where his methodical industry, shrewd sense, and literary capability were unobtrusively placed at the disposal of his fellow-workers, and are permanently in evidence in the volumes of the Yorkshire Geological Society published during his long editorship. His chief original work is contained in papers published by the same Society on the Evolution of the Don River-System, and on the Glaciation of the Don and Dearne Valleys.

James Henry Howarth, elected a Fellow in 1893, was an esteemed member of the perennial band of busy Yorkshiremen who find in the open-air pursuit of our science their relaxation from the pressure of affairs. Born at Kirby Malham on June 14th, 1854, he was educated at Giggleswick School. At the age of sixteen he entered upon his life-long career in banking, and by virtue of his sterling character and sound judgment advanced step by step to the position of Chairman of Directors & General Manager of one of the big banking institutions of the West Riding, with his headquarters at Halifax. An active member of the Yorkshire Geological Society, serving for some years as its Treasurer and for a short time as Honorary Secretary, he participated energetically in the investigations carried on by its members into the Ice-borne Boulders of the county and into the Underground Waters of North-West Yorkshire. He was joint author of several reports on these subjects, and prepared an exhaustive summary and review of the 'Boulder' records, which was published in 'The Naturalist,' 1908. As a prominent citizen and Justice of the Peace, he took a full share in

all the duties of communal life, social, administrative, and philanthropic, so that the loss of him is felt in many circles. After a period of failing health, he died suddenly on March 8th, 1918.

Daniel Jones, whose name has been associated with the geology of the Shropshire coalfields for the last half-century, was born in South Staffordshire on May 8th, 1836, and was educated in London and Berlin. From 1853 to 1866 he was associated with his father and grandfather in the management of their ironworks and collieries in South Staffordshire and South Wales. Succeeding to some of the family estates situated near Shifnal, on the eastern border of Shropshire, he was able early to devote himself to the pursuit of geological and mining interests, and in 1869 was appointed an Assistant Commissioner on the first Royal Coal Commission. The results of his investigation of the Wyre-Forest Coalfield were embodied in the Report, issued in 1871. In that and the previous year he published also papers on the sulphur springs of Chillington and Codsall Wood, on the correlation of the South Staffordshire and Coalbrookdale Coalfields, on the *Spirorbis* Limestone in the Wyre-Forest Coalfield, on the denudation in Carboniferous time of the Coalbrookdale Coalfield, and on the correlation of the Clee-Hill and Coalbrookdale Coalfields. In 1894 he embodied his knowledge of the Wyre-Forest Coalfield in a valuable paper, in which he showed the important effects of denudation in Carboniferous time on the productive Coal Measures of that coalfield.

Daniel Jones's unrivalled knowledge of the coal-bearing districts of South Staffordshire and the Welsh borders proved of great value to the mining industry, not only in preventing useless expenditure, but also in directing enterprise to suitable localities.

His interests were not confined to these practical applications of his favourite science. From 1872 until 1914 he served as Employees' Secretary to the Midland Iron & Steel Wages Board, and held the secretaryship of the South Staffordshire Ironmasters' Association. He fostered the early Volunteer movement, encouraged local agricultural societies, served as a Commissioner of Taxes, and took his seat on the bench of magistrates. He was a Fellow of this Society from 1869 until 1910.

A man of fine culture, wide sympathies, and liberal outlook, he will be greatly missed by those whose geological studies of his native district received his ever-ready encouragement. He died in his 83rd year on November 23rd, 1918, and was buried at Donington near Albrighton. [T. C. C.]

Henry Robert Knipe, elected a Fellow in 1912, was born in 1855, and died at his residence in Tunbridge Wells on July 26th, 1918. Impressed, as all imaginative minds must be, by the slow majestic history of the Earth and living things revealed in the rocks, he attempted to express his feeling in poetic form, and sought the aid of skilled and scientifically competent artists to provide fitting illustrations. The combined result was a handsome volume, published in 1905, entitled 'Nebula to Man'; and this was followed in 1912 by a similarly-illustrated volume in prose, 'Evolution in the Past,' in which the panorama of Life was deftly reviewed. Works of this kind, appealing primarily to the imagition, have more influence than is generally recognized, in attracting recruits to the severer studies which underlie them.

John Watson, elected a Fellow so recently as 1917, was born in the North of England in 1842, and spent most of his life at Newcastle-on-Tyne, where he was Managing Director of Portland Cement-Works. On retiring from business he went to live at Cambridge, and spent his leisure in the study of building-stones, marbles, and other structural materials, journeying far and wide in search of specimens to make his collection as nearly complete as possible. This collection he presented to the Sedgwick Museum, and continued to devote himself to its arrangement, cataloguing, and enlargement. Two descriptive catalogues written by him—'British & Foreign Building-Stones' and 'British & Foreign Marbles & other Ornamental Stones'—have already been published, and another, on Slates, Limes, & Cements, was in course of preparation at the time of his death, which happened at Cambridge on July 3rd, 1918, from the effects of a severe fall. In 1911 the University of Cambridge conferred on him the honorary degree of M.A., in recognition of his services to Economic Geology.

William Edward Balston, who had been a Fellow since 1872, was educated at Eton and at University College, Oxford, and was deeply interested in all branches of Natural History. He was a generous donor of valuable fossils, both to the British Museum and to the Oxford University Museum, and in 1911 he gave to the University of Oxford sufficient funds to enable Mr. J. A. Douglas to spend two years in geological researches in Peru, chiefly along the Arica–La Paz railroad then in course of construction. The first results of Mr. Douglas's work were published in our Quarterly Journal in 1914. Mr. Balston was born at Maidstone on March 8th, 1848, and died at Barvin, Potters Bar, on December 19th, 1918.

[A. S. W.]

## The Structure of the Weald and Analogous Tracts.

Amid the turmoil of recent events, so momentous for humanity, it has not been easy to concentrate attention upon the history of the distant ages when there were no men on the Earth. But our studies of the silent past, apart from their practical consequence, have, in times like these, a particular value in releasing us temporarily from the spell of the present; and it is in this mood that I now invite your reconsideration of some familiar features in English stratigraphy.

### The Wealden Anticline.

There is no structure in Britain that is more widely known to geologists in general than the Anticline of the Weald. The distinctive rock-types and surface-features in which the structure is revealed stand out with such bold simplicity that, from the early days of our science, the Weald has been accepted almost universally for all purposes of illustration as the type of a broad uncomplicated anticline. And, if we confine our attention to the surface, no better example of the structure could be anywhere found. But, when William Topley nearly half a century ago began to consider the detailed stratigraphy of the area as a whole, in the preparation of his great memoir on the geology of the Weald,[1] he soon perceived that there were factors present which had not been taken into account in the current explanation, and that the origin and structure of this apparently slight and simple fold deserved further study. As a result of his study, he brought a short paper before this Society in 1874, entitled 'On the Correspondence between some Areas of Apparent Upheaval & the Thickening of Subjacent Beds'.[2] In this paper, he urged that the anticlinal dip of the Wealden strata might be, at least in part, accounted for without earth-movement, because of the much greater thickness of the Lower Cretaceous sediments in the axial area than on the flanks; and he showed that the same explanation could be applied to several other tracts of gently-inclined rocks in England. At the time when his paper was read, the Sub-Wealden Boring had not been carried out; and Topley pursued his argument with the

[1] Mem. Geol. Surv. 1875.

[2] Q. J. G. S. vol. xxx, pp. 186–95.

assumption that the floor of Palæozoic rocks under the South-East of England might be nearly flat; and not deeper, even perhaps shallower, beneath the Weald than at Kentish Town, where it had been struck at 927 feet below O.D. He showed that, granting this assumption, the northward dip of the Gault, from its estimated position, before erosion, of 2000 feet above O.D. on the central axis of the Weald, to its known position at more than 900 feet below O.D. at Kentish Town, was fully accounted for by the thickness of the formations that originally lay beneath the Gault in the Weald but were absent at Kentish Town. If the paper had been written after the Sub-Wealden Boring had reached its full depth, Topley might have fortified his argument by citing the further 1900 feet of Upper and Middle Jurassic rocks there proved beneath the Weald and wanting at Kentish Town; and from later borings he could have added still more to his excess-balance.

Clearly, in putting forward these views Topley realized, and was, I believe, the first to realize, the essential peculiarity of the Wealden structure—that the anticline does not persist in depth.[1] His idea that the dome might be nothing more than a great pile of heaped-up sediments, with sloping banks, gained little acceptance; and it is, in fact, disproved by the composition of some of the deposits: but his inference that the anticline occurs only in the higher formations has been abundantly verified.

During the past twenty years we have gained much new information about the underground geology of the Weald from deep borings, particularly in East Kent, where the search for coal has led to a systematic probing of the strata down to the Palæozoic floor. I have fortunately had the opportunity, in collaboration with my colleagues Dr. F. L. Kitchin and Mr. J. Pringle, of examining for the Geological Survey the cores or other material obtained from the Mesozoic rocks in most of these borings. Some of the results of this examination have already been published[2];

[1] The disappearance of the anticline underground is indicated, but without comment, in a figured section across the Weald illustrating Mr. W. Whitaker's paper 'On some Borings in Kent' Q. J. G. S. vol. xlii (1886) pl. iii, p. 46; also in a similar section in H. B. Woodward's 'Jurassic Rocks of Britain' vol. v, Mem. Geol. Surv. 1895, fig. 144, p. 298.

[2] 'On the Mesozoic Rocks in some of the Coal-Explorations in Kent' by G. W. Lamplugh & F. L. Kitchin, Mem. Geol. Surv. 1911: also 'The Underground Range of the Jurassic & Lower Cretaceous Rocks in East Kent' Appendix IV to 'Summary of Progress for 1916' Mem. Geol. Surv. 1917.

and the position of the Palæozoic platform and the effect of earth-movement upon it have been ably dealt with by your former President, Sir Aubrey Strahan, in his Address for 1913.

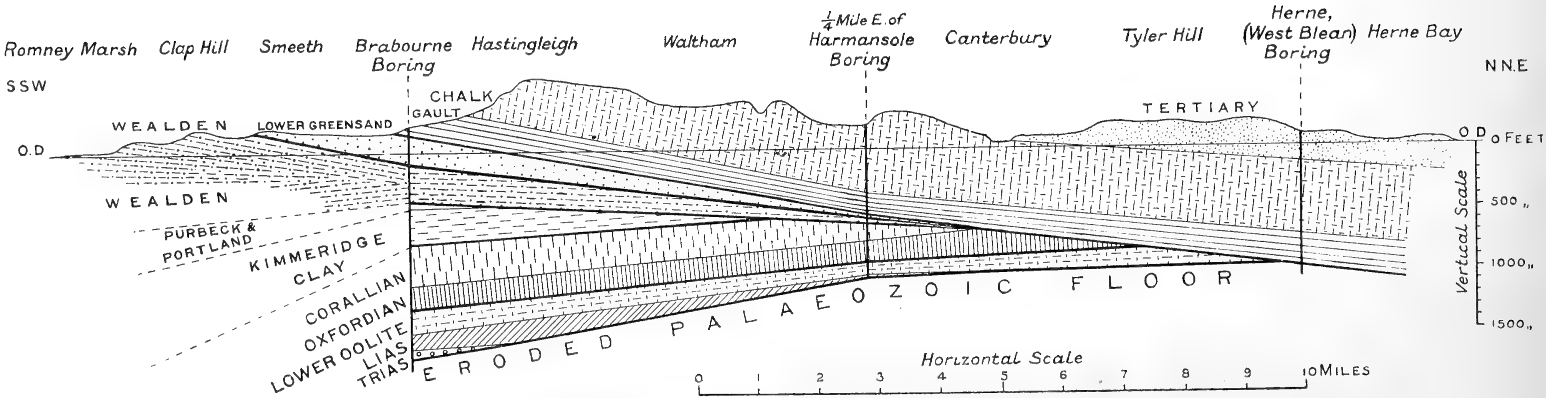
In these publications the principal features of the deep-seated geology revealed by the operations have been described, and much detailed information is given respecting the buried formations. It is my purpose now not to enter again into these particulars, but to discuss as broadly as possible the bearing of the new evidence upon the Wealden structure considered as a whole.

The borings have shown conclusively that on the northern side of the Weald the anticlinal northward dip dies out in the Cretaceous strata and is replaced in the underlying Jurassic strata, wherever these are present, by a counter-dip to the southward. The Jurassic and Lower Cretaceous formations together form a huge recumbent wedge tapering away to the north; and the northern limb of the Wealden anticline, as seen at the surface in the Upper Cretaceous rocks, is simply the slope on the upper plane of this wedge; while the lower plane, resting on the Palæozoic floor, dips downwards in the opposite direction under the Weald. The structure of this limb is illustrated by the section, fig. 1 (p. lxxvi), drawn across the North Downs from the Thames shore between Herne and Whitstable to Romney Marsh north of New Romney. As is indicated, the line traverses the position of deep borings towards both ends, and passes not far from another site near the middle. These borings supply the evidence on which this particular section is plotted; but any parallel line drawn to the eastward of this, through the district where the borings are most numerous,[1] gives almost precisely similar results, so that the section may be regarded as typical. It must be remembered, however, that in this and in the three later sections it has been necessary to exaggerate the vertical scale to about 9 times the horizontal, therefore the true dips are not nearly so steep as they are drawn; also, I have nowhere attempted to show faults or minor folds, but have merged all such details into the simpler elements of the structure. The general accuracy is not, I think, in any case seriously impaired by this broad treatment, while the essential factors are conveniently accentuated.

Without recapitulating the particulars of the succession, which have been elsewhere described, I will draw attention to the fact

[1] See sketch-map and section in my account (*supra cit.*) in 'Summary of Progress of the Geological Survey for 1916.'

Fig. 1.—*Section illustrating the structure of the northern limb of the Wealden Anticline.*



that all the main divisions of the Mesozoic sequence are represented above the Palæozoic floor in the southern half of the section; but of these, only the Upper Cretaceous rocks remain in the northern part, every formation below the Gault having tapered out northwards, partly by thinning and partly by unconformable relationships, both within and between the Jurassic and Cretaceous divisions. The structure, indeed, is precisely that foretold with astonishing insight by R. A. C. Godwin-Austen in his classical paper submitted to this Society in 1855,[1] where, in discussing the probable range of the Oolitic Series, he says:—

'These considerations suggest the probability that the Oolitic series of depositions may be wanting over an area part of which is now represented by our south-eastern counties and along a line to the north of the Wealden denudation. To what extent the Oolitic group may exist beneath the Wealden and Cretaceous groups of Kent, Sussex and Surrey, is a more difficult question; but the continuity of the old ridge [" the axis of Artois "] being granted, we may infer that, relatively as to its breadth, it exercised along our area a like influence to that it had along its continental course, and that, whilst the ascending members of the group were brought up against it by a process of successive overlap, as in the Boulonnais, so also they were abraded and denuded from above downwards, as has happened there.'

It will be seen from the figure (fig. 1) that just as the upward curve of the Cretaceous strata marks participation in the visible anticline, so the downward curve of the Jurassic strata suggests relationship to a hidden syncline.

In this section the Jurassic–Lower Cretaceous wedge has expanded southwards from zero under the Thames valley to a thickness of 1784 feet at Brabourne, a mile or two south of the Chalk escarpment, with good evidence that the maximum has not been nearly reached, since a boring at Penshurst near Tonbridge,[2] some 8 miles south of the Chalk escarpment but still on the northern side of the anticline, starting low down in the Wealden Series, proved a thickness of 1867 feet for portions of the Wealden and Upper Jurassic sequence which are represented at Brabourne by only about 200 feet. Moreover the Lower Kimmeridge Clay, not reached at Penshurst, but proved to be over 600 feet thick in a recent boring near Battle,[3] is less than 200 feet thick at Brabourne.

[1] 'On the Possible Extension of the Coal-Measures beneath the South-Eastern Part of England' Q. J. G. S. vol. xii (1856) pp. 65–66.

[2] Fully described in the above-cited Memoir 'On the Mesozoic Rocks, &c.' Mem. Geol. Surv. 1911, pp. 66–77.

[3] See 'Summary of Progress of the Geological Survey for 1916. Appendix III—On a Deep Boring made in 1907–9 at Battle.'

It is to be noted also that the outcrops of the Lower Greensand and Wealden Series north and south of Penshurst, show a thickness of over 1300 feet of strata, represented by not more than 540 feet in the Brabourne Boring. Thus, there is a proved expansion of over 3000 feet south-west of Brabourne, without taking into account the expansion of the Jurassic formations below the Kimmeridge Clay, about which at present we have little or no information. But the fact that the downward slope of the Palæozoic floor becomes steeper towards the southern end of the section suggests that the expansion of these lower formations also continues. In any case, it is certain that, as the anticline rises towards its crest, the Palæozoic floor sinks to greater depths beneath it. Even if the Middle Oolites, Lower Oolites, and Lias continue from Brabourne towards the central area without further expansion, it will mean that the Palæozoic floor between Penshurst and Battle lies at about 3500 feet below sea-level; and the probability that its depth is greater than this is increased by the incoming of a fringe of Trias at Brabourne, for the British Trias is pre-eminently a basin-formation, found usually in deep troughs of the older rocks, and often thickening rapidly from its marginal belt. The Sub-Wealden Trias, however, up to the present, has been proved only at Brabourne, so that our knowledge of it is too slight to build upon, and I therefore exclude it from the calculation.

As to the structure under the southern side of the Weald we have not much definite knowledge, but yet sufficient to suggest that the conditions are, in the main, similar and complementary to those on the northern side, and that there is here also a reversal of dip between the Cretaceous rocks at the surface and the Jurassic rocks deep underground; in fact, that the perfect anticline above covers a perfect syncline below. It fortunately happens that we know the thickness of the Purbeck, Portland, and Kimmeridge formations on the southern flank of the main axis, from the old Sub-Wealden boring and from the recent boring near Battle. The three formations are, in the aggregate, at least 300 feet thinner here than at Penshurst, and stand, moreover, at a somewhat higher level. It is certain, therefore, that somewhere between the two places, the downward plunge and expansion of these formations has been arrested and has given place to an upward curve, accompanied by attenuation: that is to say that the structure, as a whole, is synclinal. The position of the bottom of the trough has not been exactly ascertained, but may be surmised to lie rather nearer

to Penshurst than to Battle, being thus nearly coincident with the main axis of the superficial anticline (see fig. 2, facing p. lxxx).

Similarity between the opposite sides of the Weald is also to be observed in some of the outcropping strata, particularly in the Lower Greensand, which is known to thin rapidly towards the Chalk escarpment on the south, as well as on the north, dwindling from 300 to 400 feet in the Arun Valley, to only a few feet where proved in borings beneath the Gault between Eastbourne and Lewes. A corresponding, but less extreme diminution of the Wealden Beds in the same quarter is also indicated, though not actually proved, by the narrowing of the outcrops.

The southward uprise and attenuation of the Jurassic rocks towards this quarter justifies the supposition that they may thin off southwards against a rising floor of Palæozoic strata in the same way that they have been proved to do on the other side of the basin, and that the limits of the Wealden Anticline are approximately the limits of the buried syncline also. If this be so, it follows that the Palæozoic floor may be nearer the surface in the Tertiary strip south of the South Downs than it is in the Weald, an inference of some practical consequence, which might be worth putting to the test.

To illustrate this trend of the evidence, I have plotted a section across the Weald, from Sheerness at the mouth of the Medway to the Sussex coast at Beachy Head, as shown in fig. 2. The deep boring at Sheerness gives definite information down to the Palæozoic floor at the starting-point; at 8 miles to the south-south-east the line passes through the Bobbing Boring, which again entered the Palæozoic floor; and at about 18 miles, on reaching the plain of the Weald Clay, I take the evidence of the Pluckley Boring, which lies 7 miles away to the east, supplemented by that of the Brabourne Boring for the Middle and Lower Oolites and Lias not penetrated at Pluckley. It will be noticed that up to this point the section reproduces almost exactly the features shown on a larger scale in the previous section, fig. 1 (p. lxxvi), which lay 18 miles farther east.

For the central area I depend largely upon the Penshurst Boring, about 15 miles distant to the westward, projected to the line of section at the perpendicular which is also the strike of the rocks; but this boring ended in the Kimmeridge Clay, and, as before explained, the lower part of the section here is based hypothetically on the Brabourne results. Farther south, the line runs close to

the site of the old Sub-Wealden Boring and within a mile or two of the more recent Battle Boring, and the combined results of the two give positive evidence as far down as the Oxford Clay. After passing these borings the section-line is bent 20° more to the west, in order to catch the landward outcrop of the Upper Cretaceous rocks near Beachy Head. I have not ventured to prolong the hypothetical position of the Palæozoic floor beyond the northern part of the section; but the diagram, as it stands, brings out quite clearly the lenticular outline of the aggregated Mesozoic formations, and shows the essentially superficial character of the famous Wealden anticline.

With this section in view, we will resume for a moment the consideration of Topley's idea that the Wealden dome may have been an original dome of sedimentation.

The differential accumulation of Mesozoic deposits in the basin having proved to be so much greater than Topley was aware of, it might seem that his case was thereby strengthened. But, as I have pointed out in a previous publication,[1] there are, among the infilling sediments, at several horizons, deposits which possess characters denoting shallow water and approximate equality of depth over the whole area during their accumulation: as, for example, the Corallian Limestone; the estuarine band of the Purbeck; the estuarine top of the Weald Clay; the muddy sandstones of the Kellaways and Portland Beds; and the coarser sands of the Lower Greensand. The present position of these originally horizontal planes, and their relationship to each other, afford positive indication that the lenticle of sediments was accumulated in a subsiding basin, and was not piled up as a dome. The horizon-planes are not parallel, but, when drawn in section, are seen to radiate slightly, like the ribs of a partly-opened fan, with their widest expansion towards the middle of the Weald (as illustrated in fig. 1, p. lxxvi, in which some of these planes are denoted by thick lines).

We learn from them that, from early Triassic to mid-Cretaceous times, besides the general movements of elevation and depression affecting the whole region, there was a persistent local sagging or downward movement of the Palæozoic floor under the middle of the Weald, with relative stability or even sometimes uprise at the flank. Each originally horizontal plane in turn underwent this local tilting, and the effect was, of course, cumulative upon the

[1] 'On the Mesozoic Rocks, &c.' *op. supra cit.* Chapter vii, p. 88.

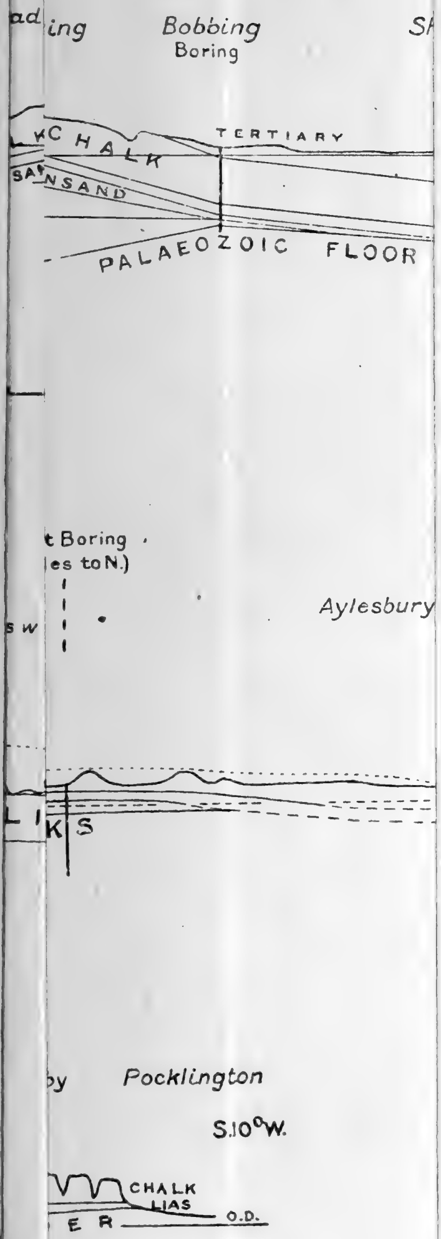

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FIG. 2.—THE WEALD.

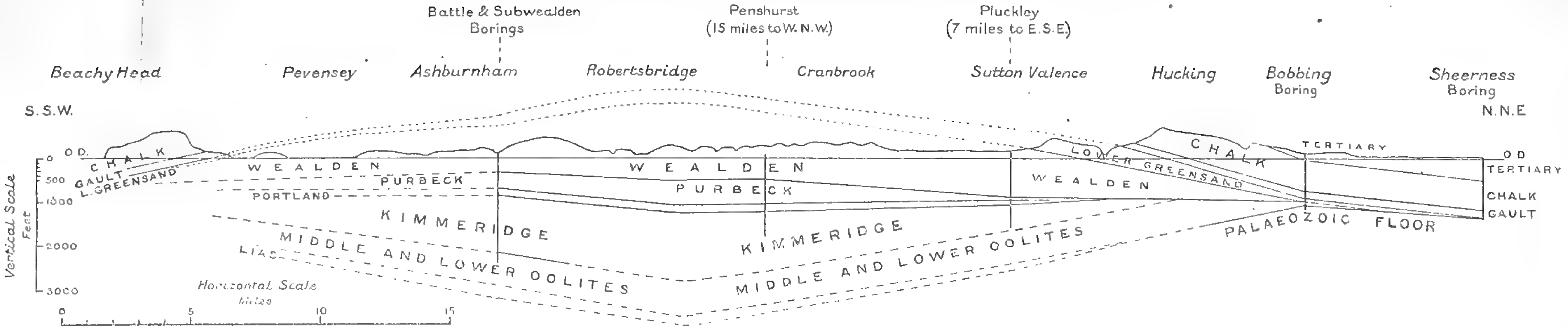



FIG. 3.—THE SOUTH MIDLANDS.

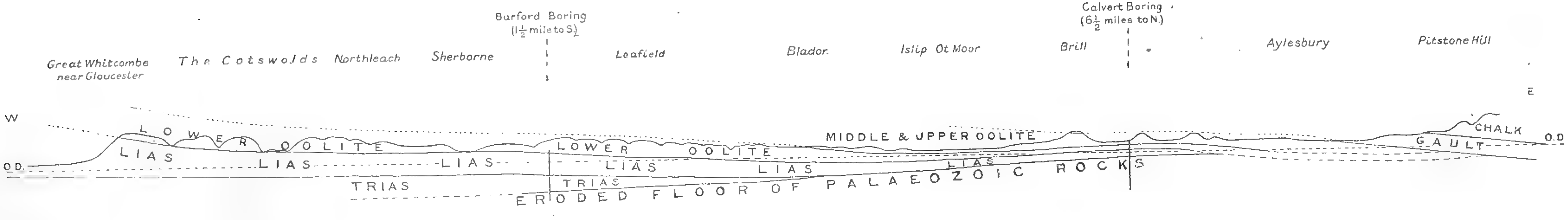
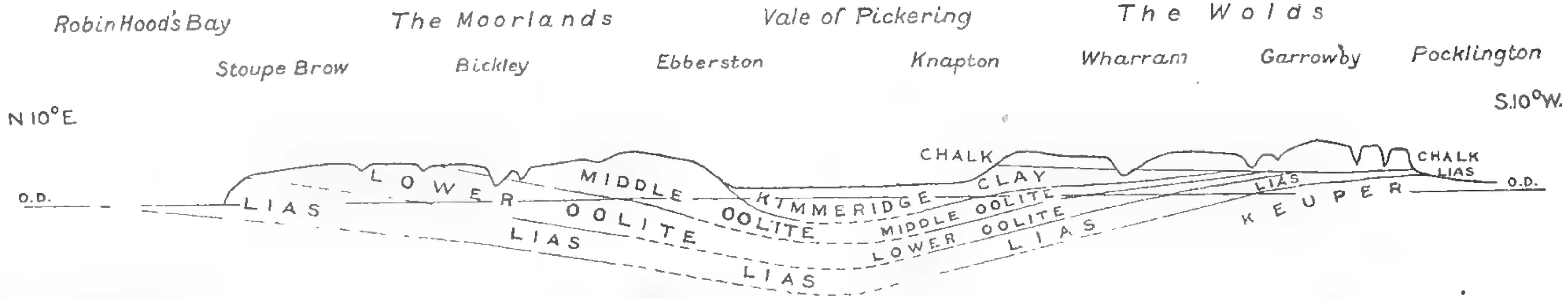



FIG. 4. NORTH YORKSHIRE.




All the sections are on the same vertical and horizontal scales. Vertical: 1 inch = 3000 feet; horizontal: 1 inch = 5 miles. The thick vertical lines represent borings.

earlier planes, so that by the beginning of the Upper Cretaceous Period the lowest plane, or that at the base of the Mesozoic sequence, had been bent down at least 5000 feet lower in the central area of the Weald than at its margin under the present Thames valley.[1] Before the end of the Upper Cretaceous Period this local subsidence appears to have been at last arrested; and in Tertiary times an opposite tendency set in, as if the basin-like droop of the floor were being stretched or hauled into a flatter curve. Through the shallowing of the basin, it followed that the uplift of the infilling sediments was greatest in the deeper part, where they were thickest; and thus, over this part, a superficial bulge was formed, now visible as the Anticline of the Weald. Topley saw that there was some connexion between the differential thickness of the beds and their anticlinal structure, but his explanation of it cannot be sustained.

The stratigraphical history of the basin, as revealed by the northern borings, presents many points of interest that I must here pass without notice, but there is one particular which it is important to mention. It is with respect to the unconformities and gaps which were found to break the sedimentary sequence at several horizons. As may be gathered from the sections shown, some of these are of great strength; for example, the Wealden beds lie across the edges of all the Oolitic formations, and pass beyond them on to the Palæozoic floor; similarly, the Oolites cross the Lias; and the Gault crosses the Wealden and Lower Greensand. But in every case where it has been possible to trace these unconformities and 'non-sequences' towards the deeper part of the basin, they have been found to weaken or to die out altogether. The Wealden at Penshurst and Battle fades down imperceptibly into the Purbeck Beds; and these by their estuarine bands afford an easy transition to the underlying Portlandian; which, in turn, merges gradually into the Kimmeridge Clay, though showing a sharp eroded junction with it at Brabourne. The obliteration of the breaks lower in the sequence cannot be similarly proved, as the mid-Wealden borings have not gone deep enough, but may be inferred, from the known setting-in southwards of the Inferior Oolite between the Great Oolite and the Lias, and from the expansion in the same direction of the Lias itself, both in thick-

[1] These conditions have been discussed by Sir Aubrey Strahan in his Presidential Address for 1913 (*op. cit.*) and illustrated by a contoured sketch-map (Pl. C); also by Dr. A. M. Davies, Q. J. G. S. vol. lxix (1913) pp. 334–38; and Mr. H. A. Baker, Geol. Mag. dec. 6, vol. iv (1917) pp. 398–403, and 542–50.

ness and in zonal range. In the Cretaceous formations the same tendency is observable; the expansion of the sandy '*Mammillatus*-Bed' at Folkestone helps partly to fill up the gap between the Gault and the Lower Greensand; and at Hythe and Redhill[1] the presence of estuarine fossils in the uppermost part of the Weald Clay modifies the sharp transition from marine to freshwater beds noted in the borings. Reverting to the simile of the fan, we may liken the stratigraphical breaks to the ribs, which are strong and close together in the handle of the fan, but thin away to nothing as they diverge.

This bald outline of the evidence regarding the Wealden basin will suffice to show that the ruling factor in its history has been a prolonged balanced sinking and contemporaneous infilling with sediments: marine, freshwater, and then again marine. The question of primary causes and the theory of isostasy are thus brought inevitably to mind, but I shall waive them in favour of a concrete matter which will be easier and perhaps more profitable to discuss, namely, the similarity of the structure in the rocks of the same age in other parts of England. It would have been enlightening also to have considered the extension of the Wealden structure over-sea in Northern France; but this, for the present, I must leave out of account.[2]

[1] 'Geology of the Weald' Mem. Geol. Surv. 1875, p. 98 (Hythe); 'Summary of Progress for 1900' Mem. Geol. Surv. 1901, p. 117 (Redhill).

[2] [Borings in the Boulonnais have proved that the Jurassic dome, which is the prolongation into France of the Wealden Anticline, is based upon a depression of the deep-seated Palæozoic floor, and that the Jurassic rocks of the dome wedge out southward, as well as northward, beneath the Chalk. The buried trough is shallower here than in Kent, and it probably reaches its eastward termination where the superficial anticline also ends. I find that this structure in the Boulonnais was described incidentally some years ago by J. Gosselet in a paper entitled 'Etude Préliminaire des Récents Sondages faits dans le Nord de la France pour la Recherche du Bassin Houiller,' published in Ann. Soc. Géol. Nord, vol. xxvii (1898) pp. 139–49, of which an English translation by Mr. L. L. Belinfante was published in Trans. Inst. Mining Eng. vol xviii (1899-1900) pp. 317–25. The following passages are quoted from the English translation (*op. cit.* p. 322):—

'Without prejudging the information which may be gained from a study of the Jurassic rocks bored through, it is already evident that the geotectonic anticline of the Boulonnais Jurassic overlies a deep depression of the Palæozoic surface. This surface indeed lies almost exactly at the same level, 425 to 460 feet below ground, at Strouanne, on the north of the Boulonnais, and at Samer, on the south. Between these two extreme points stretches a broad depression corresponding to the Jurassic dome of the Boulonnais:—

That the structure of certain other areas of sedimentary rocks in England resembled to some extent that of the Weald, was incidentally urged by Topley in the exposition of his idea that apparent dip need not imply unequal earth-movement. He cited in particular the Jurassic and Triassic rocks of Central England, and the Oolitic rocks of Yorkshire, with further illustration from the Carboniferous rocks of Yorkshire and of Derbyshire. I propose now to follow him in regard to the first two examples, with the advantage of information procured since he wrote.

## The South Midland Structure.

In the South Midland area the Jurassic sequence affords the only practicable basis for comparison, owing to our inadequate knowledge of the Trias of the Weald, although, if we could have included this formation also, I believe that the similarity of structure would have declared itself more obviously.

The great eastward attenuation of the thick sedimentary pile which constitutes the Jurassic succession in Gloucestershire and neighbouring counties was brought into prominence by Hull, in a valuable paper contributed to this Society so long ago as 1859, 'On the South-Easterly Attenuation of the Lower Secondary Formations of England, &c.,'[1] and my present discussion of the matter will be practically a restatement of Hull's case, with some additional evidence. As an illustrative section I have taken a west-to-east line from the Cotteswold escarpment above Gloucester, through mid-Oxfordshire, to the neighbourhood of Aylesbury in Buckinghamshire (fig. 3, facing p. lxxx), as this line runs close to the Burford Boring

| (Borings.) | (Depth below sea-level to Palæozoic floor.) Feet. |
|---|---|
| Strouanne | 453 |
| Tardinghen | 604 |
| Framzelle | 1306 |
| Pas de Gay | 1263 |
| Wirwignes | 689 |
| Samer | 440 |

'What is the age of this Palæozoic depression? How has a lower orographic syncline changed into an upper geotectonic anticline? These questions will be answered, it is hoped, by a study of the Jurassic rocks traversed in the above-mentioned borings.']

[1] Q. J. G. S. vol. xvi, pp. 69–81.

and near enough to the Calvert Boring to render available its definite information respecting the Jurassic sequence. Both borings reached the Palæozoic floor, and, if the line were prolonged beyond Aylesbury for 30 miles or so farther east, it would intercept the Ware Boring, in which the absence of all the Jurassic rocks was proved, the Gault resting directly upon Silurian. It is the existence of these borings, with their positive evidence, that has impelled me to adopt this line, though it is imperfectly adapted for comparison with the Wealden section on the same scale, as it traverses the strike of the Jurassic rocks obliquely, and is thereby inconveniently lengthened, while the angles of dip are correspondingly decreased. If it had been possible to take a shorter line directly south-eastward from Gloucester, I believe that the resemblance of the sections would have been much closer; but the underground geology in this direction has not yet been proved sufficiently to justify delineation.

The section now presented will, however, serve well enough for my general argument. It shows, in a less accentuated form, the same wedge-like profile of all the Jurassic formations, and the same fan-like arrangement of the dips; but with this difference, that the thick end of the wedge lies to the westward instead of to the southward. At the western end, near Gloucester, the Lias alone has a thickness of not less than 1360 feet; at Burford, 22 miles to the east, it has shrunk to 627 feet; at Calvert, 27 miles still farther east (brought to the line of section at the perpendicular), it is diminished to 240 feet, and must wedge out entirely long before Ware is reached. The Lower Oolites, at their outcrop on or near the line of section east of Gloucester, have a maximum thickness of about 600 feet, which is reduced to a little over 100 feet at Calvert.[1] Most of the Middle and all the Upper Oolites lie east of the borings, so that we do not know what their thickness may have been in the tract from which they have been stripped; but they are, together, about 800 feet thick at their outcrop along the line of section, and, if we grant them this thickness only, without allowance for westward expansion, it will bring up the original pile of Jurassic sediments in the Gloucester area to a thickness not far short of 2800 feet. At Calvert the whole pile is reduced to a thickness of about 1000 feet, and has probably wedged out altogether 10 or 15 miles farther east, partly by

[1] The Burford Boring started below the top of the Lower Oolites, and proved the remainder to be 90 feet thick, to which probably about 60 feet more should be added for the portion removed by erosion.

continued thinning and partly by erosional planing-down, as in the northern flank of the Weald. There is, however, an important difference in the attitude of the two sections, which obscures the comparison. In the Wealden section the Jurassic rocks are wholly below sea-level, and are so disposed that the plane of their uppermost portion makes the nearest approach to horizontality; while in the South-Midland section the western end is so far uplifted that the whole sequence is brought above sea-level, and the plane of approximate horizontality falls in the middle of the Lias. The whole pile is thus tilted towards the east, and has had its high-lying western portion cut away by denudation. We have strong reason to believe that the Jurassic strata, along with the Trias, originally ended off westwards in old shore-lines against the Palæozoic massif on the Welsh border, and the formations presumably became attenuated towards this margin as well as towards the east. The trough thus outlined is like that of the Weald, but from its tilted position and the reduction of its infilling strata by denudation, we cannot now determine whether the likeness was further marked by the former existence of a superficial anticline, although there is a suggestion in the general structure that this may have been the case. It is certain, at any rate, that a concealed syncline, with dips in one part counter to those at the surface, can be recognized beneath the pile, showing distinctly in the buried Liassic rocks and still better in the Trias. The reversal of dip in the deeper formations was indeed pointed out by Topley (Q. J. G. S. vol. xxx, 1874, p. 189) in the following terms:—

'We infer, for instance, because of what we know of the dip of the Great Oolite in Gloucestershire and Oxfordshire, that the beds have been upheaved towards the west and north-west, which has resulted in a dip to the east and south-east, or towards the London Basin. But if, over this area, denudation had gone much further than it has done, and all the Oolites down to the higher part of the Lower Lias had been swept away, we should observe that the beds along this line were approximately flat: and we should infer that there had been no upheaval here, or that the net results of such movements as had taken place had been to leave the beds in a horizontal position. If the whole of the Lias had been denuded, we should infer a slight *westerly* dip or *from* the London Basin. If denudation had gone far into the Trias, sweeping away the whole of the higher Secondary rocks, we might have inferred a considerable westerly dip.'

To this account we can now add the evidence of the Calvert Boring, which has proved a definite westward dip in the Lower Lias itself; otherwise the statement requires no modification.

That the South-Midland and Wealden areas have had a very similar tectonic history during Jurassic times becomes still more apparent on comparison of their sediments. These, while differing in many points of detail, present the same general characters and, in most parts of the sequence, are remarkably alike in composition. They are almost wholly of marine origin, and, in the South Midlands as in the Weald, they include at several horizons wide-spread deposits of original horizontality, which by their present divergence prove a constantly-renewed differential sinking of the western trough and an equivalent wedge-like accumulation of sediments in the depression. Nearly to the close of Jurassic times the two areas continued to maintain a close correspondence in respect to sea-level; but then there came a change and a difference, probably due to the setting-in of the western uplift, by which most of the Midland and Western tract appears to have been raised above the inundation of the great Wealden lake or estuary, and was not laden like the southern basin with a huge mass of fresh-water deposits. With the idea of compensative adjustment in mind, it is tempting to speculate on the possibility that the more elevated position of the Jurassic rocks in the South Midland area at the present day may be due to the original lack of this extra load, and to the consequent earlier removal of whatever Cretaceous cover it may have had.

The section may be taken as typical for the Jurassic rocks of the middle of England at least as far northward as the Wash, and probably up to the Humber. Everywhere in this belt the sediments as a whole have their greatest thickness and fullest sequence in the west, and become attenuated and interrupted by gaps and unconformities eastwards. Information as to their arrangement after they disappear beneath the Chalk is at present scanty, but all of it goes to show that they soon wedge out upon a rising slope of Palæozoic rocks continuous with that proved in the South Midlands. Deep borings at Culford, Lowestoft, Harwich, and other places[1] have demonstrated that they are wanting under the greater part of Essex and Suffolk, with the implication that the same condition extends well into Norfolk. In fact, wherever the boring-test has been applied in the eastern counties, it has proved that the Jurassic wedge does not extend far in under the Chalk, and that the condi-

[1] For a convenient list and summary of deep borings in the south and east of England, see Appendix to Sir Aubrey Strahan's Presidential Address for 1913, Q. J. G. S. vol. lxix, pp. lxxxiv–xci.

tions are the same as in North Kent. North of the Wash the question becomes more problematic, but the composition and structure of the Lower Cretaceous succession in Lincolnshire, and the attenuation of the Lias and Oolites, suggest an approach to the margin of the trough.

## The Yorkshire Jurassic Wedge.

Crossing the Humber, we will pass to the consideration of the other Jurassic area which Topley brought into comparison with the Weald, namely, that of the North Riding of Yorkshire; and here again we shall find that the similarity is closer than he knew. In this tract the strike of the rocks swings round, from a general northward to a general eastward trend, in fact almost resuming the direction of their hidden course in Kent. We do not gain much help from borings in this region, as the Palæozoic floor has nowhere been attained within the Jurassic tract; but the general structure is revealed in the broad outcrops of the eastern moorlands and in the fringe emerging on the eastern side of the Vale of York, where, fortunately, the Chalk escarpment crosses the strike of the Oolites and Lias, and has been cut back far enough to allow an insight into the conditions beneath it. Here again we discover that the Jurassic rocks as a whole form a huge recumbent wedge, of which the apex points southward, that is, nearly at right angles to the South Midland wedge, and directly opposite to that of the Northern Weald. For an illustrative section I take a line running from Robin Hood's Bay south-south-westwards to the edge of the Vale of York near Pocklington, which will cut off a small slice of the Chalk Wolds near the escarpment, where the evidence is clear (fig. 4, facing p. lxxx). A longer line from the mouth of the Tees south-south-eastwards to Market Weighton, perhaps better suited for comparison with the previous sections, would have shown us the same structure in a slightly less accentuated form, and more interrupted by irregular topography. In the section used, the thinning of all the members of the Jurassic sequence in the same direction is fully as marked as in the previous sections. Taking the thickness of each formation in turn as we cross its outcrop, we find that in the north the Lias measures about 900 feet, but diminishes southwards to about 150 feet before reaching the Cretaceous unconformity, and is then nearly cut out; the Lower Oolites are at least 550 feet thick at their outcrop on the moorlands, but dwindle down to not much over 100 feet before they are shaved off north of

Pocklington by the unconformity; the Oxfordian and Corallian together count some 750 feet where they can be measured in Newtondale, but have shrunk to 90 feet under the Wolds; the Kimmeridge Clay may be 600 feet thick in the Vale of Pickering but is shaved off soon after it passes beneath the Chalk. Assuming that the formations were originally continuous up to the northern limits of our section with the same thickness as at their present outcrop, there has been, in the north, a column of sediments 2700 feet thick against a column of only about 350 feet in the south; and the wedge was later sharpened down almost to a feather-edge by Cretaceous erosion. The Lias and Middle and Upper Oolites of this area are broadly similar in character and origin to those of the South Midlands and Kent; but the Lower Oolites, which bulk largely in the middle part of the wedge, are quite different, estuarine sandstones and shales taking the place of the marine beds of the south. There is clear evidence, however, that the whole sequence was deposited under the same tectonic conditions of a long-subsiding trough. Intercalated with the estuarine beds are some narrow bands of shallow-water marine sediments, which, along with the Corallian beds of the Middle Oolites, afford old horizon-planes as definite as those in the south; and these show in section the same fan-like arrangement, though with a different radiant. They demonstrate that, throughout the Jurassic Period, there has been in this area a recurrent sinking in the north and north-west with relative stability in the south and south-east.

The resemblance in structure is carried still further, for here again we find the deep syncline beneath the heaviest pile of sediments, and the uprise where the wedge thins beneath the Chalk. The bottom of the syncline underlies the Vale of Pickering, where it probably descends to at least 1500 feet below sea-level (see fig. 4, facing p. lxxx), and from this depth rises rather sharply to the south towards the pre-Cretaceous anticline at Market Weighton. But it is only on the western flank of the Wolds, by the accident of the recession of the Chalk escarpment, that this structure is revealed. In traversing the east coast from Robin Hood's Bay to Holderness, we encounter a steady persistence of southward dips, and a regularly ascending sequence from Lower Lias to Upper Cretaceous.

We cannot tell what the attitude of the Cretaceous cover may have been when it extended northwards over the syncline, but it is noteworthy that a shallow syncline in the Chalk, well brought out by the bold curve of the line dividing the flintless Upper Chalk from the flinty Middle Chalk on the Wolds, shows no correspond-

ence with the Jurassic structure, and has its axis over the thin part of the wedge, near the Jurassic anticline, in the same way that the Chalk syncline of the London Basin covers an older anticlinal area where the Jurassic rocks are thin or absent.

The general conditions in North Yorkshire are analogous to those in the South Midlands also. The present broad outcrop of the Jurassic rocks coincides roughly with a region of maximum sedimentation, and there are indications that the deposits were thinner in the north and west, where they have been removed by denudation, as well as in the south, where we can still see something of them. As in the South Midlands, the basin as a whole has been tilted by the differential uplift of the outer margin, but without altogether eradicating the original syncline.

## Comparative Thickness.

It is rather curious that, while the maximum thickness of the three Jurassic wedges which we have had under consideration is in close agreement, the thickness of the component formations varies widely. In the Weald, so far as is known, the Upper Oolites are by far the thickest elements of the wedge; in the South Midlands, and in Yorkshire, this part is played by the Lias and Lower Oolites. To bring out both the resemblance and the difference, I have arranged in parallel columns in the following table, the maximum known thickness of each Jurassic division in the three areas, on or near the lines of section.

Maximum known Thickness of the Jurassic Rocks in the three Sections (figs. 2, 3, & 4, facing p. lxxx).

| Formation. | I. Weald. (*Borings.*) | II. South Midlands. (*Outcrops.*) | III North Yorkshire. (*Outcrops.*) |
|---|---|---|---|
| | feet. | | |
| Purbeck ............ | 562[1] | 10 | — |
| Portland ............ | 141[2] | 80 | — |
| Kimmeridge ......... | 1273[3] | 300 | 600 |
| Corallian ............ | 342[4] | — | 350 |
| Oxfordian ............ | 191[4] | 450 | 410 |
| Lower Oolites ...... | 194[4] | 600 | 550[5] |
| Lias .................. | 140[4] | 1360 | 870 |
| | 2843 | 2800 | 2780 |

[1] Penshurst Boring. [2] Battle Boring. [3] Sub-Wealden Boring.

[4] Brabourne Boring; the thickness of these divisions is probably greater in the middle of the Weald, but has not been proved.

[5] West of the Peak Fault; east of this fault, the thickness is about 100 feet greater.

The approximation of the three totals must, of course, be more or less fortuitous, seeing that the items represent only our present knowledge, and may have to be altered, particularly in the Wealden section, if borings should ever be made through the deeper parts of the basins. But, in a broad way, the correspondence of the figures must imply an almost equal amount of differential subsidence in the three areas between the beginning and the ending of the Jurassic Period.

It has been generally recognized that the middle of England was covered by a shallow sea during the accumulation of the Oolites; and an obvious deduction to be drawn from the facts which I have summarized is, that through all the Jurassic Period there existed a steadily deepening trough which swept in a bold curve from north to south, bulging towards the west, with land not far distant on both sides; and that the history of the development and obliteration of this trough has been nearly the same in all parts of its course. The infilling and sinking have gone on for a very long time in apparent association, as if due to compensative adjustment; but, in all cases, there has been a final recovery which was greatest where the deposits were thickest. This recovery implies a shallowing of the trough, and may have been due to a stretching of the floor with consequent reduction of the curvature.

In tracing out these structures in the Jurassic and Cretaceous rocks, I have been tempted to look for them in the older formations also, particularly as Topley, following Hull, found some similarity of structure in the Triassic rocks as well as in certain areas of Carboniferous strata. A good case could indeed be made out for the principle of the infilled basin and the differential recovery in nearly every English stratified formation, but the evidence is generally imperfect, and not worth pressing. I will content myself, therefore, with touching briefly upon a few salient points of resemblance.

The Trias of the Midlands, as Hull and Topley observed, thins rapidly in a south-easterly direction, and we have learnt now from borings that it wedges out in this direction sooner than the Jurassic rocks. This condition prevails probably as far north as the Wash, but may be modified farther north, as a deep boring at Market Weighton [1] in South Yorkshire has recently revealed an unexpected thickness of Trias and Permian in a quarter where

[1] Described by Dr. W. Gibson in 'Summary of Progress for 1917' Appendix I, Mem. Geol. Surv. 1918, pp. 42–45.

the Jurassic strata are reduced to their northern minimum. Throughout the Midlands, however, we can be sure that the Trias occupies a trough parallel to, and in part coincident with, that of the Jurassic, and we have proof that the two systems behave very similarly in their underground prolongation. The subsiding area appears to have had nearly the same bounds during both periods, but the trough of greatest depression (and therefore of thickest accumulation) seems to have lain farther west in the earlier period than in the later. The two masses of sediment are quite different in character and mode of formation, but they have followed the same regimen in obliterating the hollows of continued subsidence. In both cases, also, the later reversing uplift was most pronounced along the tracts in which the deposits were respectively thickest; that is to say, where the collecting troughs were deepest. It is this differential recovery in the middle of the basins that has brought about the prevalence of dips towards the attenuated borders, which impressed Topley and led to his speculation upon the cause.

The Carboniferous rocks of Derbyshire and Yorkshire are cited by Topley as affording further examples of attenuation (again south-eastwards) rapid enough to produce a perceptible dip. Our knowledge of these rocks has been greatly extended lately by borings that have traced their eastward prolongation beneath the Permian and Trias, of which an excellent account has been given by my colleague, Dr. W. Gibson.[1] It is now known that, south of the Humber, the concealed Coal Measures combine with the outcrop to form a tilted syncline, which is fringed underground on the east and south by the lower divisions of the Carboniferous System, as it is on the west and north by the outcrops of these divisions. The bottom of the Lower Carboniferous rocks has not been reached, nor has their eastward termination been proved; but the evidence points to their original attenuation in this direction, and to the probability that the Carboniferous wedge comes to an end under the present Jurassic belt, partly from this cause, but mainly through being shorn off by the Permian unconformity. All the divisions thicken as they approach the region of the Pennine uplift, and it appears certain that this great anticline has arisen on the site of a former trough of depression and maximum sedimentation.

[1] 'The Concealed Coalfield of Yorkshire & Nottinghamshire' Mem. Geol. Surv. 1913.

From the character and relations of the deposits, it has been generally recognized that they were accumulated in an area of differential subsidence, and Mr. Cosmo Johns,[1] in discussing this matter, showed that the coal-seams can be used for measuring the direction and amount of the differential movements by the method which I have since used in the Jurassic rocks.

The coalfields of the Midlands afford evidence of local and irregular subsidences and re-elevations in the same great belt, but the northern basin appears to have become shallow and broken to the south, and the structures are disconnected and complex. On the whole, however, they appear to indicate that the centre of depression in Carboniferous times lay farther west than afterwards, so that the Carboniferous, Triassic, and Jurassic basins of the Midlands, though in part confluent, had their greatest depths ranging in order from west to east, like the present outcrops.

Farther south-westward, the Carboniferous field of South Wales is another example of a tilted syncline in which strong differential movement during the period is implied by the arrangement of the rocks; and of this area it is remarked by Sir Aubrey Strahan 'that there may be some connection in shape between the present Carboniferous basin and the area of subsidence in which the maximum development of the Carboniferous rocks took place.'[2]

Beyond the Carboniferous basins it is not safe to pursue the argument, as we know so little about the concealed areas of the older rocks, and to consider only the exposed tracts would be manifestly unsound. But I cannot help suspecting, on general considerations, that the great piles of Devonian, Silurian, and Ordovician rocks of the Welsh borderland may mark the positions of sedimentary basins which have been filled and upheaved, and that the very fact of the persistence of the piles is an indication that they represent the thicker parts of the original formations. This brings me to a corollary arising from the study of the wedge-structures, which I think may be of wide application.

[1] 'On Differential Earth-Movements during Carboniferous Times, & their Significance as Factors in Determining the Limits of the Yorkshire, Derbyshire, & Nottinghamshire Coalfield' Proc. Yorks. Geol. Soc. vol. xv (1905) pp. 372–79.

[2] 'The Geology of the South Wales Coalfield: Part II—The Country around Abergavenny' Mem. Geol. Surv. 1900, p. 19; see also 'The Coals of South Wales &c.' *ibid.* (2nd ed.) 1915, pp. 81–83.

## Persistence of Outcrop in relation to Thickness.

The corollary is, that the present outcrops of the formations involved in the structure coincide more or less closely with the tracts in which the formations severally attained their greatest original thickness. This appears to be a general rule wherever any such formation rises wholly above present sea-level, but it may not apply where the formation lies wholly or mainly below that level. The recognition of this relationship in the Jurassic outcrops of the Midlands was incidentally stated by Hull in his paper of 1859 (Q. J. G. S. vol. xvi, 1860, p. 77) in the following terms:—

'It is scarcely possible to estimate the advantage, both to science and to civilization, which has resulted from the present configuration of the Mesozoic rocks of England. Keeping in mind the tendency which they exhibit to thin away to the south-east, it is evident that, with their present strike and inclination, they are presented to us in succession along lines of fullest development. In order to estimate this more fully, we have only to reflect how dwarfish would have been the ascending series of formations, had they been upheaved along an axis coinciding with the present escarpment of the Chalk from Reading to the German Ocean.'

That Hull's statement applies with equal force to the Trias, Lias, and all the Oolites, not only of the Midlands but of the North of England also, is evident from the sections that we have been considering (figs. 3 & 4, facing p. lxxx); and needs no further comment. The same condition is even more strikingly apparent in the Lower Cretaceous succession, in which the great Wealden Series, as we have seen, dwindles to nothingness away from its outcrop; and the marine Lower Greensands have been found to diminish almost as rapidly underground wherever the boring-test has been applied. The Chalk affords a further example, although under different circumstances. In this case the thickest part of the formation is on the east below sea-level, and the mass becomes thinner in every subdivision when traced westwards up to the present escarpment. That it continued to lose thickness in this direction may be safely assumed; and, although we cannot be certain of its original limits, there are indications, in the composition of the lower portions, that they at least, and probably the whole formation, wedged out against the ancient uplift of the western country. Therefore the existing outcrop represents the thickest part of the original mass now above sea-level. The same argument will hold good, I believe, in every particular, for all the Tertiary strata of the south

and south-east of England, and is not without its application to the present distribution of the Glacial deposits.

I have already hinted at the probable bearing of the factor on certain occurrences of our Older Palæozoic rocks, but shall not venture farther in this direction, for reasons previously mentioned. It seems, indeed, possible that the principle, with some limitations dependent upon variability of rock-structure, may be of universal application, since it is evident that, when denudation plays upon a sedimentary mass of irregular thickness without other inequality of conditions, it is the thinnest parts of the mass that will first disappear and the thickest parts that will endure longest. Formations accumulated in a subsiding trough or basin are necessarily more or less lenticular in profile, so that, if brought at any time equally under the influence of erosion or denudation while still unprotected by later formations, they will lose area most quickly around the margin and will maintain it longest in the middle of the lenticle. In the English examples under consideration the lenticles have been tilted, so that one side only has been exposed and lost, with the result that the remaining portions take the form of wedges, in which the thick end sustains the present outcrop.

The same conditions must have been operative during every cycle of erosion, and may have been effective at several different periods on the same formation. Therefore the existing masses of strata, considered broadly and without reference to exceptional circumstances, may be logically held to denote by their survival that they represent the thicker parts of the original formations.

This is the assumption which I had in mind before, in mentioning the Older Palæozoic rocks of Wales. If I were to go still farther afield, I believe that I could gather a big body of evidence in support of it, along with some which would tell against it. But the point does not require elaboration; it is obviously true as regards the English Mesozoic rocks, and must be applicable in other regions of similar history. Indeed, it may possibly have already received more recognition than I am aware of.

In concluding, I will rehearse the main steps of the argument which I have sought to pursue.

1. The Anticline of the Weald is a superficial structure dependent upon an underlying syncline. The lenticle of sediments thus bounded was deposited in a gradually deepening trough, which was afterwards shallowed by partial recovery.

2. The Jurassic rocks of the rest of England have had a similar history, and show an analogous structure, modified by unequal uplift.

3. The Triassic and most of the Carboniferous rocks of England appear also to have been accumulated in deepening troughs or basins, which were afterwards shallowed by differential uplift where the deposits were thickest.

4. Where the formations dealt with lie above sea-level, the present outcrops represent the areas of maximum development, and therefore coincide roughly with the position of the deepest parts of the old troughs. This factor may be of wide application, and has a practical bearing.

February 26th, 1919.

Mr. G. W. Lamplugh, F.R.S., President, in the Chair.

Carlos Bentos Freire d'Andrade, A.R.S.M., A.R.C.Sc., 28 Calhariz de Bemfica, Lisbon (Portugal); Lieut. Charles Robert Hacon, M.C., Machine Gun Corps, 122 Rosehill Road, Ipswich; and Lieut. Frank Tinley Ingham, B.Sc., A.I.C., Lincolnshire Regiment, Middle Rasen, Market Rasen, were elected Fellows of the Society.

The List of Donations to the Library was read.

The President said:—

The Fellows will be aware from the Special Notice which they have received that it is proposed to change the subject previously announced for this afternoon's meeting, and I hope that the change will be approved.

When it was found that our distinguished Fellow, Col. T. W. Edgeworth David, was to be detained in London for a few days by the delay of the troopship on which he returns to Australia, we felt that this was an opportunity not to be missed of obtaining from him, if possible, some account of the personal experience that he has gained during the last three years in the application of geological knowledge to the War on the Western Front. The Officers of the Society therefore approached Col. David, and he very kindly consented to act upon our suggestion, although I fear that it may have been a most inconvenient encroachment upon his time.

Col. T. W. Edgeworth David, D.S.O., C.M.G., D.Sc., F.R.S., then proceeded to deliver his lecture on 'Geology at the Western Front.'

A vote of thanks was unanimously accorded to Col. David for his lecture, and he made a brief reply.

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March 12th, 1919.

Mr. G. W. Lamplugh, F.R.S., President, in the Chair.

Charles Ferdinand Zabel, 3 Priory Gardens, Bedford Park, W.4, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communication was read by Mr. R. D. OLDHAM, F.R.S., in the absence of the Author:—

'The Early History of the Indus, Brahmaputra and Ganges.' By Lieut. Edwin Hall Pascoe, I.A.R.O., M.A., D.Sc., F.G.S., Superintendent, Geological Survey of India.

Dr. A. SMITH WOODWARD, F.R.S., F.L.S., F.G.S., exhibited, and made some comments on, Fish-remains from the Upper Devonian (Pickwell-Down Sandstones) of Woolacombe Bay (North Devon), discovered by Mr. Inkerman Rogers, and noticed by him in the 'Geological Magazine' for March 1919.

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March 26th, 1919.

Mr. G. W. LAMPLUGH, F.R.S., President,
in the Chair.

Robert Campbell, M.A., D.Sc., F.R.S.E., Lecturer on Petrology in the University of Edinburgh, 7 Muirend Avenue, Juniper Green (Midlothian); Capt. James Alfred Goodwin, R.E., A.R.S.M., Highstead, Sittingbourne (Kent); Herbert William Greenwood, Trinity House, Macclesfield (Cheshire); Frederick Thomas Maidwell, 103 Greenway Road, Runcorn; and George Horace Plymen, B.Sc., 33 Herbert Gardens, Harlesden, N.W. 10, were elected Fellows of the Society.

The List of Donations to the Library was read.

At 6 P.M. a Special General Meeting was held, in order to consider the following Resolution of Council:—

'That it is desirable to admit Women as Fellows of the Society.'

The PRESIDENT said:—

It will be within the recollection of most of the Fellows that the question of the admission of Women to candidature for the Fellowship of the Society has been raised on more than one occasion in the past. It was considered in 1889 and 1901, and again, more systematically in 1908–1909, when a poll of the Fellows was taken and three Special General Meetings were held, with inconclusive results.

It is generally recognized that the course of events since these dates has materially changed the situation. Women have been welcomed to our meetings as visitors, and we have had many examples of their qualifications for Fellowship in the excellent papers which they have from time to time contributed to the Society. The value of these papers has been appreciated by all

geologists, and has been repeatedly acknowledged by the Council in its Awards.

Therefore, in the opinion of the Council, it is no longer reasonable to maintain a sex-bar against qualified candidates for the Fellowship of the Society, and I am empowered by the Council to submit the above-mentioned Resolution for your consideration.

A ballot was then taken, and the Resolution was declared carried by 55 votes against 12.

The following addition to the Bye-Laws was then proposed:—

> Section XXIII. *Interpretation.*—In the interpretation of these Bye-Laws words in the masculine gender only, shall include the feminine gender also.

A ballot having been taken, this addition was carried by 50 votes against 5.

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April 9th, 1919.

Mr. G. W. Lamplugh, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'The Section at Worms Heath (Surrey), with Remarks on Tertiary Pebble-Beds and on Clay-with-Flints.' By William Whitaker, B.A., F.R.S., F.G.S. With Petrological Notes by George MacDonald Davies, M.Sc., F.G.S.

Pebbles and Chalk from Worms Heath were exhibited by Mr. W. Whitaker and Mr. G. M. Davies, in illustration of their paper.

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May 7th, 1919.

Mr. G. W. Lamplugh, F.R.S., President, in the Chair.

Francis Henry Ahier, Bronallt, Caradoc Road, Aberystwyth; George Little Brown, M.I.M.E., The Rescue Station, Yorke Street, Mansfield Woodhouse (Nottinghamshire); Lieut. William Arthur Edwards, R.G.A., 11 Stracey Road, Harlesden, N.W.10; Marshall Henry Haddock, The Technical College, Doncaster (Yorkshire);

Capt. Harold Virgo Hinton, Brynheulog, Forrest Road, Penarth (Glamorgan); Charles William Osman, M.Inst.C.E., Highfield, Chagford (Devon); Norman Mosley Penzer, B.A., 12 Clifton Hill, St. John's Wood, N.W. 8; and Inkerman Rogers, Inkerman House, Clovelly Road, Bideford (Devon), were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT said:—Major R. W. Brock, formerly Director of the Geological Survey of Canada, was called upon last year to undertake on behalf of the War Office an arduous journey in Palestine, during which he had to devote particular attention to the Dead Sea region. At the request of the Officers of the Society, Major Brock has kindly undertaken to tell us something of his observations in that country. It is needless to say that the region is of surpassing interest to geologists, and I am sure that the Fellows will appreciate the opportunity of hearing how its remarkable features have impressed so acute and experienced a field-geologist.

Major REGINALD W. BROCK, M.A., F.G.S., then proceeded to deliver his lecture on the Geology of Palestine, his observations being summarized as follows:—

The following formations are recognized:

| | | | | |
|---|---|---|---|---|
| QUATERNARY. | Alluvium. | Dunes; Valley and Plains Clay, and Silt; Desert Crust. | | Heavy volcanic flows, basalts, ashes, tuffs, etc. |
| | Diluvium. | Terrestrial. | Lisan Formation (Jordan-lake-beds). | |
| | | Marine. | Upper Calcareous Sandstone & Limestone. Lower Calcareous Sandstone. | |
| TERTIARY. | Pliocene. | Lacustrine. | | |
| | Eocene. | Nummulitic Limestone. | | |
| MESOZOIC. | Cretaceous. | Upper | Senonian: Danian, Campanian, Santonian | volcanics, basalts. |
| | | | Turonian | |
| | | | Cenomanian. | |
| | | Lower | Nubian Sandstone. Jebel-Usdum formation (?). | |
| | Jurassic. | On Lebanon and Hermon only. | | |
| PALÆOZOIC. | Carboniferous. | Possibly south-east of the Dead Sea. | | |
| | Cambrian. | Dolomite and sandstone. | | |
| PRE-CAMBRIAN. | Volcanics and arkose. | | | |
| | Red granites and porphyries. | | | |
| | Grey granites, gneiss, and crystalline schists. | | | |

The structure was shown to be that of a tableland bisected by a great rift-valley (graben), and flanked by a coastal plain. A section was exhibited illustrating East Jordanland acting as a horst; the boundary-faults of the Jordan Trench; the unequal sinking of the contained blocks; the western section of the tableland sunken with relation to the eastern, and thrown into an asymmetric anticline the limbs of which rise in steps through monoclinal flexures or faults.

Lantern-slides were used to illustrate the character of the country and outstanding features in its geology, more particularly the following:—the dependence of the topography upon geological structure, slopes depending on the attitude of the rocks and elevation upon the raising or depressing of fault-blocks or on lava-flows; basins and sunken areas in the tableland; the scarps bounding the Jordan Trench, especially the western fault, and fault-blocks in the Trench or against its walls that have not sunk equally with others; the upturned block of Jebel Usdum which, with the Dead-Sea bottom and the block north of Jericho, indicates a median fault between the boundary-faults; the interbanding of the Jebel-Usdum salt with sandstone and shales that resemble Nubian Sandstone; the unconformity of the Jebel-Usdum formation with the Jordan lake-beds (Lisan formation) which, with the chemical composition of the salt (lack of bromine, etc.), shows that it is not a Jordan lake-deposit; high lake-terraces in the centre of the Trench, with corresponding ones north of Tiberias and south in the Araba Valley, showing that the Jordan lake stood 1400 feet above the present Dead Sea, and that there has been no marked warping since their formation; old gravel-filled cañons of the Arnon and Terka Main which prove that the level of the Dead Sea before Jordan-lake days stood at about its present level, and that climatic conditions must have been about the same, also that it did not long precede the Jordan lake; the Lisan formation of the Jordan lake-beds, thin layers of mechanical and chemical sediments veneered along the Jordan river with fluviatile clays; 'bad-land' topography near the wadis and in the Lisan formation: narrow box cañons of the wadis in the Jordan Trench, and the more open valleys above producing a sort of 'hanging valley.'

In the main, Blanckenhorn's recent work was confirmed, in particular the fault forming the western border of the Trench and disturbances and sinking in the tableland; but new points were mentioned, such as the evidence of a median fault within the Trench; the sea-cliffs of Lisan and Jebel-Usdum; the wave-cut shelf and the salt of Jebel Usdum; the tilting of the Jebel-Usdum block and its independence from and unconformity with the old lacustrine beds; lack of disturbance and of warping since their deposition; the age and former level of the Old Dead Sea and the recent rise in the present sea, the latter indicating an increase in moisture and not drier conditions as generally supposed.

A vote of thanks was unanimously accorded to Major Brock for his lecture.

May 21st, 1919.

Mr. G. W. LAMPLUGH, F.R.S., President,
in the Chair.

Margaret Chorley Crosfield, Undercroft, Reigate (Surrey); Frank Debenham, B.A., B.Sc., 48 Lensfield Road, Cambridge; Gertrude Lilian Elles, D.Sc., Newnham College, Cambridge; Percy Evans, B.A., Burmah Oil Company, Postbox 459, Calcutta; Maria Matilda Ogilvie Gordon, D.Sc., 1 Rubislaw Terrace, Aberdeen; Mary Sophia Johnston, 90 Wimbledon Hill, S.W. 19; Cyril Ewart Leese, B.Sc., Grammar School, Camelford (Cornwall); M. Jane Longstaff (*née* Donald), F.L.S., Highlands, Putney Heath, S.W. 15; Alexander Halley Low, M.A., 9 Holland Park, W. 11; Alexander Miers Macgregor, B.A., Stamford Brook House, Hammersmith, W. 6; William Angus McIntyre, Lieut. R.E., B.Sc., Assoc.R.C.Sc., 18 Leinster Avenue, East Sheen, S.W. 14; Rachel Workman, Lady McRobert, B.Sc., Colney Park, Radlett (Hertfordshire); Mildred Blanche Robinson, B.Sc., 5 Gledhow Gardens, S.W. 5; and Ethel Gertrude Woods (*née* Skeat), D.Sc., 5 Barton Road, Cambridge, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Silurian Rocks of May Hill.' By Charles Irving Gardiner, M.A., F.G.S. With an Appendix by Frederick Richard Cowper Reed, Sc.D., F.G.S.

2. 'The Petrography of the Millstone Grit Series of Yorkshire.' By Albert Gilligan, D.Sc., F.G.S.

Rock-specimens and fossils from May Hill were exhibited by Mr. C. I. Gardiner in illustration of his paper; pebbles from various rock-formations with microscope-sections were exhibited by Dr. A Gilligan in illustration of his paper; and specimens of labradorite from Labrador were exhibited by Mr. James Francis, F.G.S.

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June 4th, 1919.

Mr. G. W. LAMPLUGH, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Dentition of the Petalodont Shark, *Climaxodus*.' By Arthur Smith Woodward, LL.D., F.R.S., Pres.L.S., F.G.S.

2. 'A New Theory of Transportation by Ice: the Raised Marine Muds of South Victoria Land (Antarctica).' By Frank Debenham, B.A., B.Sc., F.G.S.

Jaws of the Petalodont Shark, *Climaxodus* sp. nov., from the Calciferous Sandstone of East Kilbride (Lanarkshire), were exhibited by Dr. A. Smith Woodward in illustration of his paper.

Sheet 16 (Belfast) of the Geological Survey of the Union of South Africa (Scale, 1 inch = 2·347 miles), 1918, presented by the Union Department of Mines & Industries, was also exhibited.

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June 25th, 1919.

Mr. G. W. Lamplugh, F.R.S., President,
in the Chair.

Edward Philip Binet, J.P., A.M.Inst.C.E., Krugersdorp (Transvaal); David Rees Davies, Corsican Villa, Blackwood Road, Blackwood (Monmouthshire); Sidney Clarke Ells, Ottawa (Canada); John Singleton Green, Hythe (Kent); Herbert Penn Herbert, c/o Messrs. Cox & Co., 16 Charing Cross, S.W. 1; Richard George Hewitt, B.Sc., 198 Birkby Hall Road, Huddersfield; William Henry Arthur Lawrence, B.A., 81 Belsize Lane, Hampstead, N.W. 3; George Parsons, B.Sc., 13 Colville Terrace, Beeston Hill, Leeds; Catherine Alice Raisin, D.Sc., Bedford College, Regent's Park, N.W. 1; Margaret Flowerdew Romanes (*née* Macphee), Oldway, West Byfleet (Surrey); Edward George Staples, Polesdown, Hungerford (Berkshire); Enoch Oliver Taylor, B.A., B.Sc., 157 Church Street, Edmonton, N. 9; Harold Thomas, M.A., The Manse, Dogley Lane, Fenay Bridge, Huddersfield; William van Bonde, M.A., Grey University College, Bloemfontein (Orange Free State); John Thomas Wattison, 122 Rua da Restauração, Oporto (Portugal); and Richard Vernon Wheeler, Eskmeals (Cumberland), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Outlines of the Geology of Southern Nigeria (British West Africa) with especial reference to the Tertiary Deposits.' By Albert Ernest Kitson, C.B.E., F.G.S., Director of the Geological Survey of the Gold Coast.

2. 'Notes on the Extraneous Minerals in the Coral-Limestones of Barbados.' By John Burchmore Harrison, C.M.G., M.A., F.G.S., F.I.C., and C. B. W. Anderson.

Rock-specimens and fossils were exhibited by Mr. A. E. Kitson, in illustration of his paper.

A Special General Meeting was held before the Ordinary Meeting, at 5 P.M. The PRESIDENT addressed the Fellows present in the following words:—

The reasons for the action of the Council implied in the alteration of the Bye-Laws now proposed are so obvious that they hardly require statement. The unavoidable increase in all the establishment expenses of the Society has most seriously reduced the sum available for its publications. It will have been noticed that, in the Estimates for the current year, the sum that could be allotted for the Quarterly Journal was £650, only about two-thirds of the sum expended in years preceding the War; meanwhile the cost of printing and materials is at present trebled, with no prospect that it will return to the pre-war standard in the future. The threatened impairment of the function of the Society as a publishing medium has been anxiously considered by the Council, and as a step towards meeting the situation it is proposed to raise the Annual Contribution of Fellows elected after the present session to Three Guineas, with an equivalent advance in the Composition Fee. The price of the Journal to outside subscribers will also be raised.

I will now formally propose that Section VI, Articles 2 & 6 of the Bye-Laws shall be altered to read as follows:—

SECTION VI.—*Contributions of Fellows.*

2. The Annual Contribution to be paid by Fellows shall be Three Pounds Three Shillings, due on each successive 1st of January, and payable in advance for the current year. Fellows elected before November 1st, 1919, shall be liable for an Annual Contribution of Two Pounds Two Shillings.

6. A Fellow may at any time compound for future Annual Contributions, that of the current year inclusive, by payment of Fifty-Two Pounds Ten Shillings.

If he (or she) has already paid the Contribution for the current year, or any part of it, such payment shall be reckoned as forming a portion of the Composition. The Composition-fee for Fellows elected before November 1st, 1919, shall be as follows:—if elected before November 1st, 1877, Twenty-One Pounds; if elected on or after November 1st, 1877, Thirty-One Pounds Ten Shillings; or if elected on or after November 1st, 1894, Thirty-Five Pounds.

The foregoing resolution was balloted for, and carried with one dissentient.

The suggestion of the Council to revert next Session to the hour of 8 P.M. for the Ordinary Meetings was then submitted for consideration, and by 25 votes to 13 the Fellows present decided to maintain the hour of meeting at 5.30 P.M.

THE

# QUARTERLY JOURNAL

OF

# THE GEOLOGICAL SOCIETY OF LONDON.

VOL. LXXV

FOR 1919.

## 1. *On the* DENTITION *of the* PETALODONT SHARK, *CLIMAXODUS*. By ARTHUR SMITH WOODWARD, LL.D., F.R.S., Pres. L. S., F.G.S. (Read June 4th, 1919.)

[PLATE I.]

THE dentition of the Petalodont sharks is still very imperfectly known. It has hitherto been satisfactorily observed only in the highly-specialized *Janassa bituminosa* from the Upper Permian (Kupferschiefer and Marl Slate) of Germany and England.[1] Nearly all the other species and genera are represented in collections merely by isolated teeth. It is, therefore, of interest to examine the comparatively well-preserved dentition of a new Lower Carboniferous Petalodont, which has been kindly lent to me by Dr. William Eagle Clarke, Keeper of the Natural History Department of the Royal Scottish Museum, Edinburgh. The specimen was obtained from the Calciferous Sandstone of Calderside, near East Kilbride (Lanarkshire), and was presented to the Royal Scottish Museum in 1892 by Mr. John B. Wise, of Glasgow. It was regarded by the late Dr. R. H. Traquair as belonging to a new species of *Janassa*, which he named *J. wisei*,[2] but it has not so far been described or discussed.

The hard shale in which the two jaws are preserved has split

[1] A. Hancock & R. Howse, Ann. & Mag. Nat. Hist. ser. 4, vol. v (1870) p. 47 & pls. ii–iii; O. Jækel, Zeitschr. Deutsch. Geol. Gesellsch. vol. li (1899) p. 259 & pls. xiv–xv.

[2] R. H. Traquair, Brit. Assoc. Handbook, Glasgow, 1901, p. 513 (name only).

along the plane of the mouth, so that the dentition of each is exposed from the oral aspect, as shown in Pl. I. Of the cartilages only fragments remain behind and partly below the teeth, especially in the wider of the two jaws (which is here regarded as the upper). Nearly all the teeth seem to be present in the narrower or supposed lower jaw; but some of the small anterior teeth are broken away from the front of the opposing jaw, and a few of these are seen adhering to the matrix behind the 'lower' symphysial dentition (Pl. I, fig. 3, $x$). Sufficient points of contact are preserved between the two slabs, to show that in fossilization the narrower jaw was pushed a little forwards beyond the wider jaw.

The teeth are closely arranged in antero-posteriorly directed series, interlocking by alternation, and most of them must have been borne on a very stout symphysis. Only the outer paired series extends farther backwards over the ramus of the jaw. At the back of the symphysis, the one jaw is not much wider than the other; but behind this the narrower dentition shows a marked constriction, and its paired outer series of teeth extending over the mandibular rami, as preserved, is much less divergent than the corresponding series in the wider dentition. There may be some displacement by crushing.

In the wider dentition (Pl. I, fig. 1), which by reference to *Janassa bituminosa* may be regarded as upper, the teeth at the back of the symphysis much resemble those from the Carboniferous Limestone of Derbyshire named *Climaxodus imbricatus* by McCoy.[1] They are in three antero-posterior series, one median and one paired, and those of two transverse rows seem to be about equal in size. The concave hinder face of the crown in these teeth is nearly as deep as wide, tapering rather rapidly to a bluntly-rounded apex, of which the roughened surface evidently denotes wear during life The base-line of the crown descends in the middle almost in the shape of a loop, and it is marked by five concentric imbrications, of which the upper two are more widely spaced than the others. Though antero-posteriorly compressed, as usual, the dental crown is moderately thick, and its convex anterior face is shown to have been of very little depth, the basal imbrications in one broken tooth being visible not far below the apex. Except in a small part of the anterior face, which is dense (and black in the fossil), the whole of the crown consists of highly-vascular dentine (white in the fossil) traversed by large vertical canals. So far as can be determined from the broken remains, the three teeth of the next (or third) transverse row forwards are nearly similar to those just described and not much smaller, but in them the highly-vascular dentine forms only the core of the crown. The root is obscured in all these teeth. Farther forwards there are fragments of much smaller teeth, of which three examples in one transverse row are

[1] F. McCoy, in Sedgwick & McCoy, 'British Palæozoic Rocks . . . . & Fossils,' London & Cambridge, 1855, p. 620 & pl. iii G, fig. 5; A. S. Woodward, Catal. Foss. Fishes Brit. Mus. pt. i (1889) p. 38 & pl. i, figs. 1–2.

comparatively well preserved on the opposing slab of shale (fig. 3, *x*). These teeth are again about equal in size. As shown in oral view (Pl. I, fig. 2 *a*), the apex of the crown has been well worn during life to a slightly-convex lozenge-shaped face, of which only the transverse long axis is formed by the highly-vascular dentine. The smooth anterior face of the root is exposed (fig. 2 *b*), and it is seen to taper gradually downwards; in the best-preserved specimen it appears to be truncated below and somewhat less deep than wide. The teeth of the single paired series flanking the prehensile symphysial teeth (fig. 1) are much wider than the latter, with the elevation of the crown reduced to a low ridge, to which the highly-vascular dentine is restricted. This ridge is inclined forwards, and still placed so near the front of the crown that its comparatively deep concave posterior face forms the greater part of the oral surface of the tooth. The ridge is usually blunt, perhaps partly the result of wear, but in one posterior tooth there is a trace of coarse serration at its ends. The basal imbrications are from five to eight in number, and they are sometimes interrupted at the bluntly rounded ends of the teeth. Nine of these teeth occur in undisturbed series on each side, diminishing in size forwards; five are behind the symphysial dentition, with their long axis inclined slightly outwards and backwards.

In the narrower dentition (Pl. I, fig. 3), presumably lower, most of the teeth are more imperfectly exposed, but nearly all seem to be present. The space occupied by the prehensile teeth on the symphysis is actually wider than that in the opposing jaw, the flanking blunt teeth being narrower. The back transverse row of the symphysis (fig. 4) resembles that of the opposing jaw, except that the middle tooth of the three is larger. The next transverse row, which is a little displaced and broken, comprises five teeth, of which the middle one is much the largest, though smaller than that behind; the tooth of the inner paired series also much exceeds in size that of the outer paired series. The broken apex in these teeth shows that the highly-vascular dentine is restricted to the hinder face. The third row forwards again consists of five teeth, similar in structure and proportions to those of the second row, but all somewhat smaller. These are very much broken, and the teeth of two still smaller transverse rows farther forwards, also evidently consisting of one median and two paired series, are so much battered that their precise characters cannot be determined. It can only be stated that the highly-vascular dentine is restricted to a small patch in each. There is thus evidence of four transverse rows of prehensile symphysial teeth in five antero-posterior series, succeeded behind by one transverse row of three larger teeth. The blunt teeth of the series flanking the symphysis are scarcely more than half as large as those of the opposing jaw, but they are more numerous, eight or nine bordering the symphysial teeth already described, while four nearly similar teeth continue the series farther back round a peculiar small constriction. Their characters are not well shown (fig. 3); but they are transversely elongated, and

consist mostly of the dense dentine (black in the fossil). In continuation of this series of small teeth on each side over the mandibular ramus, there are five teeth closely similar to those of the opposing jaw and nearly as large. The coronal ridge of highly-vascular dentine is especially conspicuous; and in one of the back teeth on each side, where unworn, it bears a trace of the coarse serration (Pl. I, fig. 6) already noted in one of the opposing teeth. Two of these teeth detached from the matrix are interesting, as showing the shallow but relatively-large root, which is scarcely overhung by the crown in any part. The antero-inferior face of the root (Pl. I, fig. 5*a*) is gently convex and smooth, tapering below where it ends in a series of five short blunt radicles. The posterior face, also smooth, is nearly vertical and shallow (as shown in cross-section, Pl. I, fig. 5*b*).

Scattered round the jaws on the shale are some remains of coarse shagreen, the granules being very irregular in size and shape; but all possess a shining convex outer surface. The granules (figs. 7–9) are usually quadrilateral with rounded angles, sometimes ovoid, sometimes indented or coarsely crimped round the margin. Most of them are smooth, but some behind the symphysial dentition are crossed by fine parallel grooves, and a few farther back bear traces of concentric ridging. Very similar shagreen has already been described in the Upper Permian *Janassa bituminosa*, and is well seen in an example of this species in the British Museum (Natural History), No. 43424.

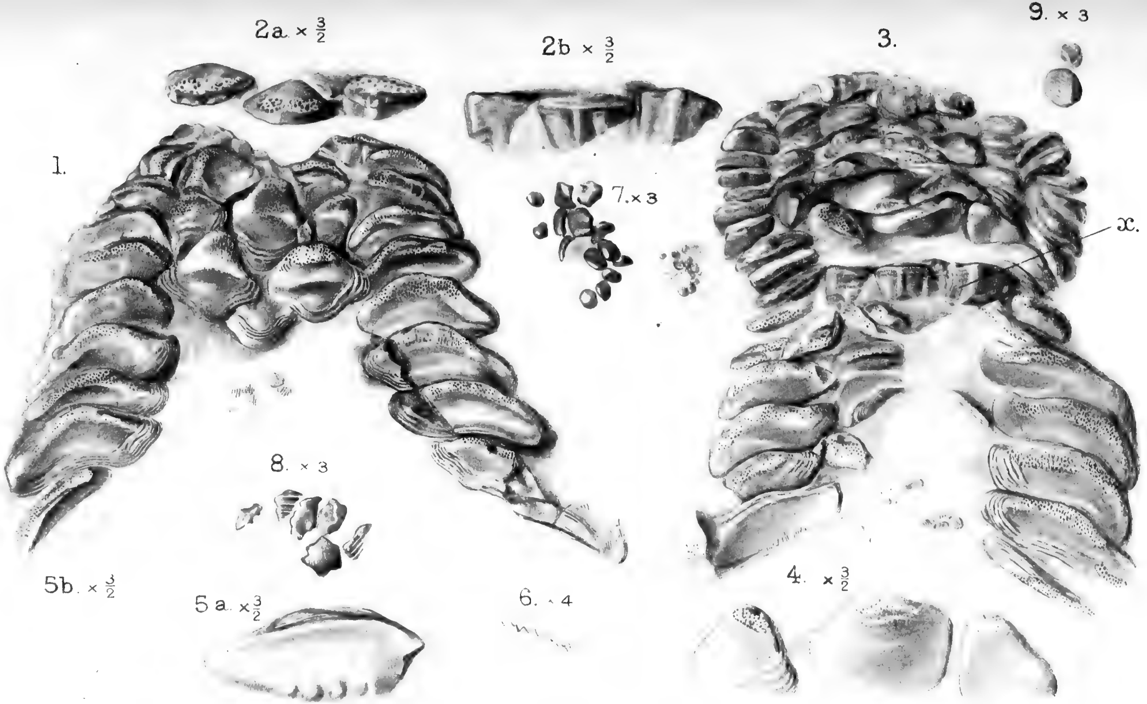
With an extensive nomenclature based on isolated teeth of uncertain relationships, it is difficult to name the specimen now described even generically. As, however, the teeth at the back of the symphysis are essentially identical with those from the Lower Carboniferous of Derbyshire referred to the type species of *Climaxodus*,[1] it is probably best to assign the specimen to this genus. The only earlier name given to teeth much resembling those in the fossil is *Chomatodus*[2]; but on the original evidence this could never be defined, and the type species, *Chomatodus cinctus*, is almost certainly a Cochliodont, not a Petalodont. Later names for nearly similar teeth are *Peltodus*[3] and *Tanaodus*,[4] and it is interesting to notice that under the second St. John & Worthen have grouped a series of isolated teeth representing most of the variations seen in the new fossil. From all the described comparable teeth the hinder symphysial teeth in this fossil are distinguished by the peculiar tapering shape of the crown. The specimen therefore represents a new species, which may be appropriately named *Climaxodus wisei*.

[1] *Climaxodus imbricatus*, F. McCoy, *loc. jam cit.*

[2] L. Agassiz, 'Recherches sur les Poissons Fossiles' vol. iii (1838) p. 107. See also references in A. S. Woodward, Catal. Foss. Fishes Brit. Mus. pt. i (1889) pp. 218–28.

[3] J. S. Newberry & A. H. Worthen, 'Geol. Surv. Illinois—Palæontology' vol. iv (1870) p. 362.

[4] O. St. John & A. H. Worthen, *ibid.* vol. vi (1875) p. 367.




G. M. Woodward, del.

Bemrose Collo, Derby

CLIMAXODUS WISEI, sp. nov.

*Climaxodus* has been commonly regarded as identical with *Janassa*; but, if *C. wisei* be correctly named, it is now clear that they are two distinct genera. In the typically Lower Carboniferous *Climaxodus* all the teeth seem to have been retained in the mouth throughout life, while of the symphysial teeth only the apical edge can have been functional. In the typically Upper Permian *Janassa* only a single transverse row of teeth was in function at one time, the older transverse rows being thrust beneath to form a supporting base; while in all the teeth the corrugated hinder face was extended, and must have been as useful for grinding as the recurved apical edge for cutting.

The dentition of *Climaxodus wisei* is especially remarkable for the discrepancy in size between the foremost and the hindmost teeth on the symphysis of the jaw, proving that there were only about five or six teeth in succession during the greater part of the life of the individual. Even the highly specialized *Janassa bituminosa* is known to have had only seven or eight teeth in succession from early youth to maturity. This is in marked contrast to the condition in all ordinary Elasmobranchs, in which the successional teeth are very numerous and rapidly replaced—a condition as evident in the Palæozoic Cladoselachidæ, Pleuracanthidæ, and Edestidæ as in the recent sharks and skates. The same limited tooth-succession, however, is also to be observed in the Lower Devonian *Protodus*, in the Carboniferous Cochliodonts, and perhaps in the Carboniferous Psammodonts. It must, therefore, have been a characteristic of many Palæozoic Elasmobranchs, distinguishing them sharply from those groups which survived until later times.

Finally, most of the teeth of *Climaxodus wisei* are interesting as exhibiting a restricted area of highly-vascular dentine much resembling a tritor in the dental plate of an ordinary Chimæroid. A relationship between some of the Palæozoic Cochliodonts and the early Mesozoic Chimæroids has already been remarked upon by P. de M. Grey Egerton[1] and O. Jækel.[2] The presence of an apparently Chimæroid character in Elasmobranch teeth which are noteworthy for their slow and scanty succession may, therefore, have some special significance.

## EXPLANATION OF PLATE I.

Fig. 1. *Climaxodus wisei*, sp. nov.; upper dentition, oral view, natural size.—Calciferous Sandstone; Calderside, near East Kilbride (Lanarkshire). [Royal Scottish Museum, Edinburgh.]

2. Do.; transverse row of three front teeth of the same jaw, oral (*a*) and anterior (*b*) views, three-halves of the natural size.

3. Do.; lower dentition of the same specimen, oral view, natural size. $x$=transverse row of three anterior teeth of the opposing jaw (see fig. 2).

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[1] Q. J. G. S. vol. xxviii (1872) p. 236.

[2] Trachyacanthidæ, O. Jækel, Sitzungsb. Gesellsch. Naturf. Freunde, Berlin, 1890, p. 130; also *ibid.* 1891, p. 127.

Fig. 4. *Climaxodus wisei*, sp. nov.; posterior view of the hindmost transverse row of symphysial teeth of the same jaw, three-halves of the natural size, partly obscured.

5. Do.; left lateral tooth of the same jaw, in anterior view (*a*) and cross-section (*b*), three-halves of the natural size.

6. Do.; portion of serrated edge of lateral tooth of the same jaw, four times the natural size.

Figs. 7–9. Do.; various granules of shagreen of the same specimen, three times the natural size.

## 2. *The* SECTION *at* WORMS HEATH (SURREY). *With* REMARKS *on* TERTIARY PEBBLE-BEDS *and on* CLAY-WITH-FLINTS. By WILLIAM WHITAKER, B.A., F.R.S., F.G.S., late of the Geological Survey. *With* PETROLOGICAL NOTES *by* GEORGE MACDONALD DAVIES, M.Sc., F.G.S. (Read April 9th, 1919.)

CONTENTS.



### I. HISTORY AND LITERATURE OF THE WORMS-HEATH OUTLIER.

THE occurrence of outliers of the Lower London Tertiaries far away from the main mass, in the Chalk-tract of Surrey, was known to Prestwich, and the sites of some of them were noted by him, though not in his papers read to the Society.[1] But, presumably because he was then dealing with distance from the main mass and not with size, these sites included only small patches, at the top of the Chalk-escarpment of the North Downs and not the much larger outlier with which we are especially concerned, roughly a square mile in area and some way inward from the Chalk-escarpment.

All these outliers consist wholly of the uppermost of the three divisions of the Lower London Tertiaries, to which the name Blackheath Beds has been given, the underlying Woolwich Beds and Thanet Beds being absent. This was not mentioned by Prestwich, who was dealing with the Lower London Tertiaries as a whole and not with the divisions thereof, the details of which, moreover, had not been then fully worked out, his third paper on the Series not appearing until 1854.

The first recognition of the Tertiary tract of Worms Heath was on Sheet 6 of the Geological Survey Map, published in 1864, though the Surveyor (who need not be named) was mistaken as to the age of the deposit when he first saw the place, some years before that date, the pebble-beds being taken as a peculiar kind of Drift, rather than Eocene, until a greater knowledge of them,

[1] 'Water-bearing Strata around London' 1851, p. 135.

over a large tract of country, showed their true age. They were at first, therefore, marked on the map only by the engraved words 'Pebble Gravel.' This mistake was corrected in a later issue of the map, when the beds had been mapped and an acknowledgment of it had been made to the Society.[1]

The first description of the outlier was given in fifteen lines of a Geological Survey Memoir,[2] based on the one good section that had been seen, and that description holds the field, so far as it goes, no trace of the Chalk having been shown.

It was many years later ere the section was again noticed in print, through a visit of the Geologists' Association, and then but little added, the only notable thing being the occurrence of supposed allophane.[3]

Seven years later another excursion of the same body led to another short description, by Mr. N. F. Robarts, which added a record of pipes in the Chalk being shown in a pit at Nore Hill, southward of the great pit at Worms Heath.[4]

Two or three years later, I know not exactly when, the cutting-back of the pit, carried close to the southern side of the high road, showed something that was new and unexpected, the Chalk being found to rise up suddenly, from beneath the Blackheath Beds, until in places it came within a few feet of the ground-surface—of course, in a very irregular way.

One of the pipes being singularly like a well, or artificial hole in the Chalk, the attention of Mr. Reginald Smith, of the British Museum, was drawn to this, with a view of having it investigated from an antiquarian point of view. I had the pleasure of going to the place with him, in the autumn of 1908, and, after careful examination, we came to the conclusion that it was worth while to have some amount of excavation done, so as to settle the question, though we thought that a natural origin of the hole was more likely than an artificial one.

The work was carried out by the Surrey Archæological Society, with the following result.

'Some experimental excavations during the year [1908] were also made on behalf of the Society on Worms Heath, where a circular shaft in the chalk outcrop on the side of a gravel pit appeared to be of such symmetrical formation as to suggest the possibility of its being due to human agency. After descending to some depth, though the remarkable symmetry was well maintained, the absence of any pick-marks in the sides and of any trace of human implements convinced the experts present that the shaft was the result solely of natural causes, and the work . . . was abandoned.'[5]

It is satisfactory to have had this point cleared up, the more so perhaps, as some old pits on the other side of the road have been marked as earthworks on the 6-inch Ordnance Survey Map.

[1] Quart. Journ. Geol. Soc. vol. xxii (1866) p. 420.

[2] 'The Geology of the London Basin' Mem. Geol. Surv. vol. iv (1872) p. 257.

[3] Proc. Geol. Assoc. vol. xv (1898) p. 459.

[4] *Ibid.* vol. xix (1905) p. 134.

[5] 'Surrey Archæological Collections' 1910, p. xi.

Of course, it was not long before the Geologists' Association paid a third visit to the new section, and in the description of this there is a view of the then most clear and interesting uprise of the Chalk, from a photograph by Mr. T. W. Reader.[1]

In 1915 yet another excursion was made, but it called for no detailed notice, as there was little change in the section, though the pit had been cut back. A valuable addition to our knowledge was made known by the finding of 'a fine *Micraster* of the form typical of the zone of *M. cor-testudinarium*,'[2] thus fixing the Chalk exposed as well down in the Upper Chalk.

The last printed word on Worms Heath is by Mr. G. M. Davies, who has given the result of mineralogic examinations of loam, sand, and sandstone from the Blackheath Beds and has noticed the supposed allophane.[3]

The above entries, so far as I know, show all the literature of the outlier, except for casual remarks and for the account of a Geologists' Association excursion in November 1918, printed since this paper was written.

## II. Description of the Section.

I turn now to the consideration of the present state of the large pit, by the southern side of the high road, which has furnished the text of nearly all the descriptions mentioned; the most westerly part that has been recorded is also the deepest, and it is there that the crimson colouring of the pebble-beds, especially shown in the large mass of conglomerate, was most striking. But this part (on the east) has been abandoned for some years, so that the section is greatly hidden, and it will pass into a like overgrown state to the older part of the pit farther south-eastwards. As a result of this abandonment the brilliance of the colouring has decreased, presumably because the hæmatitic state of the iron of the cementing material has been changed, through exposure, to a limonitic one, or that bright brown has mostly displaced the deep red of a comparatively fresh section.

Just north-westward, where the uprise of the Chalk was first seen (in 1908), work has also been given up more lately, so that the section has become less clear. The pinnacle of Chalk figured in 1910 is greatly hidden, and the larger mass some yards westward has also suffered; but it is still probably the best place for finding Chalk-fossils, the exposure of Chalk being larger than elsewhere.

Immediately westward, however, and barely divided from what we may call the Chalk-pit, a most interesting section has been opened up, showing some wonderful pipes in the Chalk, filled with pebbles, sand, and Clay-with-Flints. The bottoms of these pipes were not reached, and the sides, sometimes irregular but sometimes

[1] Proc. Geol. Assoc. vol. xxi (1910) pp. 472, 473, & pl. xxxiv.
[2] *Ibid.* vol. xxvi (1915) p. 288.
[3] Trans. Croydon Nat. Hist. Soc. vol. viii (1916) pp. 74, 75, 83, 92.

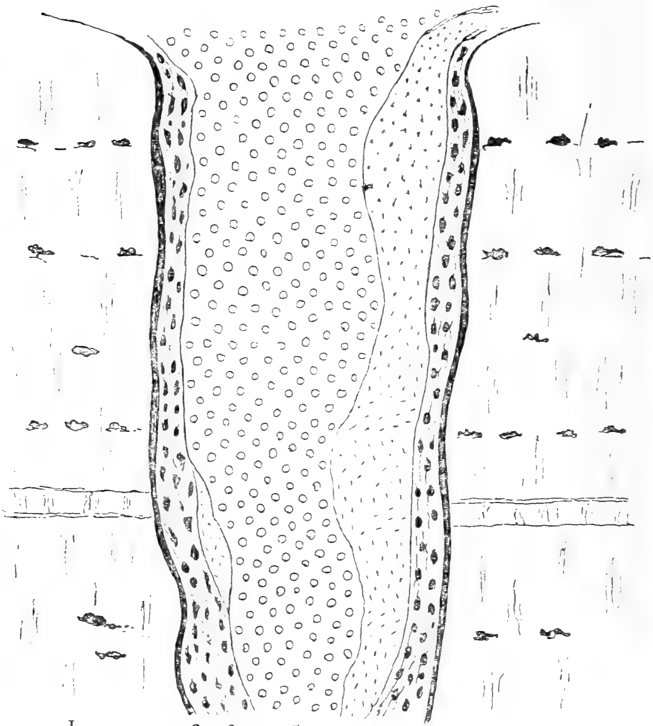
fairly even, were vertical, so that their formation is all the more difficult to explain.

The whole set of beds seen in the various pits in the outlier is as follows. All occur in the parts of the pit above described that are still to be seen, and all but the surface-layer fill the pipes in the Chalk :—

Soil and an irregular surface-layer of flints, etc.

| | |
|---|---|
| BLACKHEATH BEDS. | (5) Well-rolled flint-pebbles, in a more or less sandy matrix; sometimes hardened into a massive brown or crimson conglomerate. |
| | (4) Fine sand, usually light-coloured; but sometimes hardened into a brown iron-sandstone. |
| CLAY-WITH-FLINTS. | (3) Brown and reddish loam and clay, with unworn flints; sometimes with flint-pebbles from the overlying beds; sometimes with streaks of grey. Up to a few feet in thickness. |
| | (2) Grey clay, a thin layer, up to more than a foot in thickness. |
| UPPER CHALK. | (1) Mostly firm, jointed, with flints. A marked, hard, cream-coloured layer, neither top nor bottom well-marked, which reached a thickness of about 2 feet near the bottom: this, as well as the flints, had but a slight dip. |

*Diagrammatic section of pipes at Worms Heath.*



1 2 3 5 4 3 2 1

Unfortunately, I failed to get a good photograph of the section, and so, to make the description clearer, I have drawn a diagram-section, as was done on the black-board when this paper was read. The figure, of course, does not show any one particular pipe; but, to the best of my ability and recollection, it generalizes the information given by the set of pipes. At the same time, it is not far from being a representation of the clearest and most notable pipe at the time of my visits. In the progress of excavation this has gone: the section is constantly changing.

Sometimes the Clay-with-Flints seems to be several feet thick; but this is deceptive, and, owing to the section being cut through the circumferential part of the pipe, perhaps a frequent source of error in regard to the thickness of beds seen in pipes.

It should be noted that in this section superposition is no test of relative age. The pebble-beds and sand clearly belong to the Blackheath Series: the underlying loam and clay are the same as that irregular surface-layer which occurs over so large an area of the Chalk-with-Flints, and, perhaps, is of no definite age.

Some years ago, when visiting Worms Heath with Prof. E. W. Skeats, we saw something that was new to me, in a pit at the top of the sharp south-western slope of Nore Hill. The contents of a small vertical pipe of Clay-with-Flints had been compacted while the surrounding Chalk must have been loose, so that while the latter had gone, the once-included material of the pipe had been left, as a short column a yard or more in diameter.

There have been many pits in this southern part of the outlier (Nore Hill), and a large one, apparently abandoned lately, still gives a good section, with Chalk shown in two places, in one of which it goes up to a high level. There are also pits in the western part, northward of the high road, and Chalk has been touched here too.

## III. Remarks on the Blackheath Beds.

### (*a*) London Basin.

The pebble-beds of Worms Heath do not differ from those occurring elsewhere. Practically they are composed only, so far as pebbles are concerned, of thoroughly rolled flints, varying in size from about that of a pea to a length of several inches, most of a flat ovoid shape, with a smooth surface, though this is often slightly interfered with by very shallow whitish indents, caused by the pressure of one pebble on another.

The only exception to flints (from the Chalk), so far as I know, is the very rare occurrence of pebbles of a light-brownish quartzite: as an illustration of this rarity, during a residence of about twenty-two years in Croydon, in which much time has been spent on the pebble-beds, I have found only two of those pebbles (one this year at Nore Hill), besides another on the surface below the escarpment of the North Downs, and this showed signs of having

been used by man. This rarity is further emphasized by the fact that all the quartzite-pebbles found are of fair size, all I think more than 2 inches long, so that they are the more easily seen. They are usually rather flatter than flint-pebbles of corresponding size. The late Dr. G. J. Hinde, with the help of his children, collected far more of these pebbles than anyone else in the Croydon district, and in his family they got the name of 'penny-stones,' from the monetary reward to be gained by finding them.

The origin of this quartzite is unknown, and, of course, also the number of formations through which the pebbles may have passed before reaching their Eocene resting-place. At first thought, one is inclined to consider them as having been pebbles or boulders in the Chalk; but then one would have expected them to have been accompanied by pebbles of granite and other hard rocks which have been found in the Chalk. Can it be that they are the only derived rock in the Chalk that could stand the long pounding to which the pebbles of the Blackheath Beds were subjected? And have they been found in the Chalk?

The obvious conclusion from the composition of the pebble-beds is that the water in which the pebbles were rolled touched no other formation of firm rock than the Chalk, with its comparatively indestructible flints, the quartzite-pebbles being presumably second-hand articles. But, as was pointed out in the Geological Survey Memoir of 1872, the absence of unworn or partly-worn flints shows that the deposition of the beds did not take place along a Chalk-coast, where subangular flints would far outnumber finished pebbles. The flints must have been carried along in shallow water and the well-rolled pebbles deposited in shoals far away from the Chalk from which they came.

Then the distribution of these pebble-beds is peculiar: they are almost confined to a limited area, for in mass they are present only in the eastern margin of Surrey and in the western part of Kent. Other occurrences are of small extent and in scattered positions.

The western boundary in Surrey is the Valley of the Wandle (generally dry) from Croydon southward, no sign of the Blackheath Beds having been found along the southern outcrop of the Lower London Tertiaries in the London Basin farther westward, through Surrey and Hampshire.

Eastward the pebble-beds are a marked feature in the country, up to the Valley of the Cray, and they continue to occur up to that of the Medway; but beyond this pebbles form but a small part of the division, which takes on the sandy Oldhaven character, and is better described under that name. In East Kent there is a small mass of pebbles, forming two tiny outliers, at Shottenden Hill, Selling; but elsewhere the Oldhaven Beds consist almost wholly of sand, with only a thin bed of pebbles at the bottom.

Along the northern outcrop of the Lower London Tertiaries in the London Basin there is little trace of anything that can be referred with any certainty to the uppermost division, unless the

puddingstone of Hertfordshire should turn out to belong to it: this, however, is rarely seen in place.

At Middleton, by the border of Essex and Suffolk, a sandy pebble-bed, which seems to have been dug for gravel, may represent the Blackheath Beds;[1] while at Ipswich a very narrow outcrop of sand, with some pebbles, has been classed with the Oldhaven Beds.[2]

North of the broad outcrop of East Surrey and West Kent the evidence of wells does not point to the extension of the Blackheath Beds underground far from their outcrop. The following are the only cases in which even a suggestion of the occurrence of this division has been noted:—In Surrey, where the sandy form is the more usual underground, in two wells at Bermondsey, in one well at Brixton, in six wells at Croydon (very near the outcrop, and in one case in considerable thickness), in one well at Norwood, in two wells at Penge, and in one well at Sydenham.[3]

In Kent the outcrop of the uppermost member of the Lower London Tertiaries comes much nearer to the northern boundary of the county; in great part, indeed, up to and across it; but there are several records of its presence, mostly in the Oldhaven form, under the London Clay, in wells where that formation is more than 100 feet thick, as at Allhallows, Eastchurch, the Isle of Grain (two), Lewisham, Minster (in Sheppey, three), Sheerness (three), and Upchurch.[4]

Moreover, the outcrop crosses the Thames into a small part of Essex, and along the southern part of that county the occurrence of this division (largely in its sandy form) has been recorded or suggested in the description of very many deep wells, often below a great thickness of London Clay, at the following places:—Abberton, Abbess Roding, Barking, Barling, Billericay, Bowers Gifford, Brentwood, Broomfield, Burnham, Canvey, Chelmsford, Corringham, Downham, East Ham, Eastwood, Fobbing, Foulness, Great Baddow, Great Wakering, Harwich, Heybridge, Hornchurch, Horndon, Ilford, Ingatestone, Leyton, Malden, Margaretting, Mundon, North Fambridge, Pitsea, Rainham, Shoeburyness, Southend, Stanford-le-Hope, Stisted, Vange, Walthamstow, West Ham, and Wickford.[5] Besides these, many other wells have probably passed through some representative of this division, though with the information to hand one hardly felt justified in using the name.

[1] 'The Geology of Part of N.W. Essex, &c.' Mem. Geol. Surv. 1878, p. 24.

[2] 'The Geology of the Country around Ipswich, &c.' Mem. Geol. Surv. 1885, pp. 15, 16.

[3] 'The Water Supply of Surrey' Mem. Geol. Surv. 1912, pp. 114, 115, 123, 140–143, 145, 148, 203, 209, 240.

[4] 'The Water Supply of Kent' Mem. Geol. Surv. 1908, pp. 73, 123, 143, 144, 160, 170, 192, 194–196, 211.

[5] 'The Water Supply of Essex' Mem. Geol. Surv. pp. 86, 92, 95, 101, 105, 107, 110, 112, 114, 115, 132–134, 140, 143, 144, 147–149, 159–161, 175, 176, 184, 191, 193–195, 197, 199–201, 219–222, 233, 237, 242–244, 251, 258, 260, 262–264, 266, 274, 285, 286, 293, 300, 301, 310. Although bearing the date 1916, in the middle of which year it was printed off, the issue of this Memoir was put off during the War, so that it was not in the hands of the public until late in 1918.

### (b) Hampshire Basin.

In our other great Tertiary tract, patches of pebble-beds are shown on some of the new sheets of the Geological Survey Map, but without having any special name given to them.

Starting on the west, a patch in Wiltshire has been shown at the north-western corner of Sheet 315, and apparently it should continue into Sheet 314; but, as there is no trace of it on the 6-inch Map (Wiltshire, 72, 77) it seems likely to be merely an error in colouring.

There are twelve patches near Sherfield English, in Hampshire (Sheets 315 & 299), and five others near Braishfield, also in Hampshire (Sheet 299). In the index of colours to 299, for which I believe I am answerable, the pebble-beds are placed between the London Clay and the Reading Beds, without being bracketed with either; that is, where Blackheath Beds would come in. In the index to 315 they are marked as at the top of the Reading Beds.

Another patch at Clapham, in Sussex (Sheet 317), is indexed as at the bottom of the London Clay. It is worked for gravel.

This diversity in the index of colours on the maps shows the open mind of the Geological Survey and a proper hesitation in the classification of what seemed to be a somewhat doubtful deposit. Now, when we are not dealing with isolated maps, but can take all together, I have little hesitation in claiming these pebble-beds, or nearly all of them, as belonging to the Blackheath Series, though, of course, there may be pebbles in the Reading Beds; some of the patches are mapped as directly underlying London Clay, while others are outliers. All, so far as I know, are of the same character as the beds in the like position in the London Basin; but it would be well for a search to be made for pebbles other than of flint. I can find no record of any in the Memoirs accompanying the maps in question.

## IV. Some other Eocene Pebble-Beds.

### (a) Below the Blackheath Beds.

It has been inferred that the flint-pebbles of the Blackheath Beds have been derived directly from the Chalk; but, before we accept that conclusion, it would be well to consider whether there are any older pebble-beds from which they could have come.

One of the characters of the lowest division of the Lower London Tertiaries, the Thanet Beds, is the absence of pebbles, though, of course, a stray pebble may occur. The flints of its base-bed are either unrolled, or but partly rolled.

The middle division, the Woolwich and Reading Beds, however, commonly contains layers of pebbles. These occur very generally in the greenish bottom-beds of the southern outcrop in the London Basin, where this bed rests on Thanet Sand; but, over the far larger

area where the Reading Beds rest on the Chalk, this is rarely the case, the flints being like those at the base of the Thanet Beds. It is along the northern outcrop of the London Basin, from the edge of Buckinghamshire through Hertfordshire, that pebbles are found in the bottom-bed, where it rests on the Chalk.[1]

In Hertfordshire there are also pebbles higher up in the Reading Beds; but generally in mere layers, rarely in quantity enough to warrant the name 'pebble-bed,'[2] unless we include the beds that have yielded the Hertfordshire puddingstone, which have been seen in place near Aldenham.[3]

Along the southern outcrop in the London Basin the only marked pebble-bed recorded is in Kent, next above the bottom-bed, at St. Mary's Cray, Lewisham, and Chislehurst, the greatest thickness being 12 feet, while elsewhere there is not half that amount.[4]

In the Hampshire Basin, at the far west, in Dorset, the Reading Beds take on a gravelly condition, but not altogether a pebbly one. Beds of coarse gravel, flint conglomerate, and breccia, sometimes with Greensand chert and quartz-pebbles have been grouped by C. Reid with this division.[5] These gravels, which are described as 'more like river-gravels than like beach-deposits,' seem hardly to have any connexion with the question of the origin and formation of the pebbles of the Blackheath Beds.

Now, the whole of these occurrences of pebbles below the Blackheath Beds, spread over so wide an area, show an amount of pebbles that is small, compared with the great concentrated mass of Blackheath, Bexley, Bromley, etc., so that unless (and without any justification) we suppose that there were pebble-beds beyond the present Tertiary tract, we cannot look to the Woolwich and Reading Beds for the supply of pebbles to the Blackheath Beds.

These latter, on the other hand, with their former large extension over the Chalk tract (shown by the many outliers still left), are bulky enough to have yielded the material for later pebble-beds in the Tertiary formations; but the comparatively small areas in which the Blackheath Beds now occur lead one to think that much of the later pebble-beds may have been directly derived from the Chalk.

### (*b*) Above the Blackheath Beds.

Pebbles are of common occurrence in the basement-bed of the London Clay, and layers are occasionally found in the clay itself.

[1] 'The Geology of London, &c.' Mem. Geol. Surv. vol. i (1889) pp. 192, 193, 196–200, 203, 205.

[2] *Ibid.* pp. 194, 201, 202, 207; and 'The Geology of the London Basin' Mem. Geol. Surv. vol. iv (1872) p. 227.

[3] 'The Geology of London, &c.' vol. i (1889) p. 200.

[4] *Ibid.* pp. 116, 127, 137, 138.

[5] 'The Geology of the Isle of Purbeck' Mem. Geol. Surv. 1898, pp 192–94, and 'The Geology of the Country around Dorchester' Mem. Geol. Surv. 1899, pp. 17–22.

Where the pebbly basement-bed rests directly on Blackheath Beds there can hardly be a question as to the pebbles of the former being derived from the latter.

It was said long ago by Prestwich that 'it is probable that the denuding action (which accompanied the formation of the basement-bed of the London Clay [in which he included great part of the Blackheath Beds]) . . . in places extended to the Chalk itself,'[1] though he thought that the pebbles were derived from older Tertiary Beds. A dozen years later, however, it was suggested that the large flint-pebbles, so characteristic of that bed in the western end of the London Basin, 'were derived at once from the Chalk' in a tract in which 'the London Clay sea stretched over the Chalk, where the latter was either wholly uncovered, or but slightly covered, by any older Tertiary formation.'[2]

Clement Reid spoke of 'the mass of flint-shingle which forms the basement-bed of the London Clay,' between Moreton and Turner's Puddle, at the western end of the Hampshire Basin,[3] but perhaps this deposit may be claimed as belonging to the Blackheath Beds.

The chief deposit of pebbles in the Eocene Tertiaries, above the Blackheath Beds, is in the Bagshot Series, and not altogether at one horizon. Layers of pebbles are found in various places; but masses are less frequent and of no great extent. It is these only that need now be noticed.

In the London Basin the most westerly occurrence that has been noted is in Western Berkshire, near Kintbury, at a spot called Pebble Hill on the old map (Sheet 12), a fit name that does not appear on the new one (Sheet 267). This pebble-bed (several feet thick) is far from any Blackheath Beds, and in a tract where the London Clay is thin, so that there is far less between Bagshot Beds and Chalk than is usual. Indeed, it has been inferred, from the thinning of the Reading Beds and the London Clay, that some miles farther west, at the western end of the Tertiary Beds, Bagshot Sand may rest direct on the Chalk.[4]

Another occurrence in Berkshire is in the eastern part of the county, westward of Wokingham, where the term 'Pebble Beds' is engraved on the old map (Sheet 8). In speaking of this part, in the Memoir of the new map (Sheet 268), Mr. H. W. Monckton notices the presence of 'a few minute pebbles of quartz.'[5]

A few miles farther eastward is a thin pebble-bed at Easthampstead, which has been described by Mr. H. Dewey.[6]

[1] Quart. Journ. Geol. Soc. vol. vi (1850) p. 277.

[2] *Ibid.* vol. xviii (1862) p. 269.

[3] 'The Geology of the Country around Dorchester' Mem. Geol. Surv. 1899, p. 27.

[4] Quart. Journ. Geol. Soc. vol. xviii (1862) pp. 259, 261–65, 270, 271.

[5] 'The Geology of the Country around Reading' Mem. Geol. Surv. 1903, pp. 57, 58.

[6] 'The Geology of the Country around Windsor & Chertsey' Mem. Geol. Surv. 1915, p. 34. The publication of the map (269) has been delayed by the War.

Passing into Surrey, a fair-sized mass was recorded on the old map (Sheet 7) by a boundary-line and the word 'Pebbles,' near Egham; but the new survey has wiped this out from Bagshot, and included it with Drift. To make up for this, however, the new map (269, not yet published) will show a larger mass of pebble-beds, just south, at New Egham. Judging from the Index of the 6-inch map (Surrey, 4 S.E.), this is in the lower part of the Bagshot Sand. In the Memoir on the new map quartz-pebbles have been recorded from this neighbourhood.[1]

At St. Ann's Hill, near Chertsey, a pebble-bed is again shown: at first it was classed with the Bracklesham Beds, and Mr. C. N. Bromehead looks upon some of the beds here as of that age and some as Bagshot.[2]

It is in Essex that the Bagshot Pebble-Beds are best developed, and there they overlie the sand, which is not always the case in Surrey, etc. They have been mapped at Havering, between Kelvedon Hatch and South Weald, at Brentwood and Warley, at Frierning, south-west of Writtle, at Billericay, Stock, and Galleywood (all in Sheet 1 of the old map), and were described by H. B. Woodward.[3]

Now, some of these Essex pebble-beds are only 9 or 10 miles from the broad Kentish tract of the Blackheath Beds, though some are about 18 miles away. We are, therefore, prepared for the probability of the newer beds having been derived from the older.

It is not, however, with the nearest point of outcrop of the Blackheath Beds that we are concerned, but with the probable former occurrence of those pebble-beds miles beyond the present main mass, even beyond the farthest outliers. It is in the western part of Kent and in the neighbouring border of Surrey that we find such extension, right out to the crest of the North Downs, and we have every reason to infer that it continued farther south over part of what is known as the Wealden area, including therein all the beds below the Chalk.

Clearly the Bagshot sea must have crossed over the London Clay until it reached the underlying Blackheath Beds, and most likely passed still farther to the Chalk. We may take it, therefore, that the Bagshot Beds of Essex got their pebbles from the Blackheath Beds on the south, and partly perhaps direct from the Chalk a little farther south.

This leads to the question whether we have any evidence of the thinning of the London Clay southward from Essex that is thus pointed to? It is in Essex that the London Clay reaches its greatest thickness, up to well over 500 feet, and on the northern margin of Kent there is a considerable thickness, though the very top is

[1] Mem. Geol. Surv. vol. iv (1872) pp. 315, 316; and C. N. Bromehead, 'Geology of the Country around Windsor' Mem. Geol. Surv. 1915, p. 36.

[2] 'Geology of the Country around Windsor' Mem. Geol. Surv. 1915, pp. 37, 50.

[3] Mem. Geol. Surv. vol. iv (1872) pp. 322-27; and 'The Geology of London &c.' vol. i (1889) pp. 272-79.

shown only on the east, in Sheppey, the one place where Bagshot Sand occurs in the county, and it is the western part with which we are concerned.

At Shooter's Hill, however, there would seem to be but very little of the London Clay missing, for the sandy or loamy topmost part of the formation, to which the name Claygate Beds has been given, is present. Of late years this has been carefully observed by Mr. A. L. Leach, and his work has led him to go into the question of the thickness of the London Clay, with the following result:

'The data at present available indicate 300 ft. as the possible maximum thickness . . . but this estimate is probably too great. It is, however, sufficiently clear that the London Clay of Shooter's Hill is much thinner than that of Hampstead, Essex (530 ft.), Windsor, and Sheppey (480 ft.), and that this diminution is not due to denudation but is the result of physiographic conditions prevailing during its deposition.' [1]

Now, this thinning, to the extent of 200 feet or more, between South Essex and North Kent, if continued southward would bring the Bagshot Beds on to the Blackheath Beds. Whether the decrease in thickness of the London Clay results from original deposition in thinner beds southward, or from erosion of the top beds, does not affect the question under discussion: possibly both methods may have been effective in the south, where the evidence has been destroyed.

I must own to having been somewhat shocked at first by my friend's depreciation of the London Clay; but now it is welcome.

Crossing to the Hampshire Basin, at the far west, in Dorset, we find that the Bagshot Beds have been described by Clement Reid as becoming gravelly, like the Reading Beds, but more markedly so. They contain much Greensand chert, quartz-pebbles, and subangular pieces of Palæozoic rocks, besides Purbeck rocks. Moreover, they cross over the London Clay, so as to rest on Reading Beds, and finally pass over the latter westward and rest on the Chalk. It is inferred that westward 'within a few miles at most the Cretaceous strata must have been completely overlapped.' [2] These beds, however, are unlike the pebble-beds with which we are concerned and far from any of them: indeed, they are more like Drift-gravel.

It is between the Test and the Itchen that the Bagshot Pebble-Beds occur in force, and they have been mapped, at or close to the junction of Sheets 299 & 315, at Ganger Common and Knapp Hill, while a large sheet, in which a thickness of over 20 feet may be reached, stretches from south of Hursley, over Hocombe Plantation and Hiltingburn Common to Cranbury. This is barely divided from an outlier on the east, in Cranbury Park, which again is barely divided from the outlier of Otterbourne Hill, in which the

[1] Proc. Geol. Assoc. vol. xxiii (1912) pp. 115–18, 181.

[2] 'The Geology of the Isle of Purbeck' Mem. Geol. Surv. 1898, pp. 191, 194–96; and 'The Geology of the Country around Dorchester' Mem. Geol. Surv. 1899, pp. 27–32.

best sections have been seen, to a depth of 15 feet, and some small quartz-pebbles have been found.[1]

The easternmost patches mapped are near North Boarhunt: five to the west and north-west of the hamlet, on the Rooksbury outlier; and two to the east, on the Walton-Heath outlier.[2]

At their outcrop, immediately north of all these occurrences of Bagshot Pebble-Beds, the Lower London Tertiaries show no sign of pebble-beds, with one exception on the west, where the possible Blackheath Beds at Braishfield come within 2 miles of Ganger Common. The next nearest occurrence of the older beds to the newer is near Sherfield English, where the former crop out some 4 miles west of Ganger Common.

On the other hand, in those parts of the Hampshire Basin where possible Blackheath Beds occur (and it is no matter what we call them) there are no marked pebble-beds in the neighbouring Bagshots.

Moreover, the newer set of beds is here bigger than the older. So altogether one is led to conclude that the Bagshot Beds of the Hampshire Basin got their pebbles direct from the Chalk; for the greater part, at all events. Of course, the sea that crossed over any pre-existing pebble-beds, on its way over the London Clay and the Lower London Tertiaries to the Chalk, would mop up any such that came in its way.

Of other and newer Tertiary pebble-beds there is not much to say: it is rare for any to approach the Bagshot Pebble-Beds in importance. So far as I know, the only part in which such newer pebble-beds have been mapped is in Sheet 269, of which I have been shown a MS. copy, and in the Memoir in which they have been described. Some belong to the Bracklesham Beds and some to the Barton Sand, and the latter are noticed under the heading 'Basement Pebble-Bed.' The chief masses of these are south of Sunningdale, on Chobham Common, and at Stannershill, north-east of Chobham, all in one neighbourhood, and the thickness goes up to 16 feet. Mr. H. Dewey says of them that the flint-pebbles are

'associated with a few pebbles of vein-quartz and Greensand chert. The occurrence of chert at this horizon is noteworthy, for so far pebbles of this material have not been found in any of the underlying Tertiary deposits.'[3]

## V. General Remarks on the above-described Beds.

The foregoing pages have dealt chiefly with sets of beds that may be called insignificant, mere trifling incidents in the great

[1] See 'The Geology of the Country around Winchester, &c.' Mem. Geol. Surv. 1912, pp. 56, 57; and 'The Geology of the Country around Southampton' Mem. Geol. Surv. 1902, pp. 13, 14.

[2] See 'The Geology of the Country near Fareham, &c.' Mem. Geol. Surv. 1913, p. 55.

[3] 'The Geology of the Country around Windsor' Mem. Geol. Surv. 1915, pp. 41, 43, 44, 52–55, etc.

geologic scale, of local occurrence, of little thickness, of somewhat monotonous composition, merely deposits of pebbles and sand.

They are alike in composition, being almost wholly composed of well-rolled, smooth-surfaced pebbles of Chalk-flints. The differences in them consist in the variation in the few pebbles of other rocks. Thus the Blackheath Beds yield a peculiar quartzite which has not been found in other deposits, but no quartz; the Bagshot Beds, on the other hand, yield small pebbles of quartz, but so far none of quartzite; the Barton Beds, besides quartz, yield chert from the Lower Greensand. Thus it is the highest beds only that give evidence of overlap on to Lower Cretaceous strata, the quartz and quartzite being indefinite; and this overlap is of great extent, the inferential loss of beds at the surface southward (whether by thinning or by erosion) being comparable to the loss of beds underground northward, from the Wealden area to the London Basin, though some hundreds of feet less.

Again, confining our view to the Lower London Tertiaries, looking beyond the pebble-beds, and taking the Series as a whole, we find that though it is not of mere local occurrence and varies a great deal in composition, character, and origin, yet it may be looked on as insignificant, being in many parts less than 50 feet thick and in few reaching to about thrice that thickness.

Yet the study of these small things bears on questions of great import, on erosion and overlap of considerable extent; and it may throw light on events of appreciable magnitude and wide interest, even on that highly debatable question the erosion of the Weald. For, if the general conclusions that have been here brought forward hold good, that great erosion must have started in Lower Eocene times, as, indeed, I have occasionally suggested, and the process may have been continued in Middle Eocene times. I will not enter into the question of what happened later; but it seems to me that the planing-off of the Chalk began in Lower Eocene times, though to what extent it went over the central part of the Wealden area one can hardly say.

Although much work has been done on the Lower London Tertiaries as well as on the beds above them, up to the Barton Sand, in the London Basin, there is still much to be done in various ways in the field and in the laboratory, and it has been well started with means that were not in the hands of the older workers. This work I leave to my younger brethren, content if I have dropped them a hint here and there.

## VI. Remarks on the Clay-with-Flints.

I forbear from alluding to the literature of this subject and to the various theories that have been brought forward to explain the occurrence of the material: enough now to consider that locally.

The sections that have been seen at Worms Heath, with some in other outliers of the Blackheath Beds in Surrey, are of interest in regard to the Clay-with-Flints, that irregular material (which

can hardly be called a deposit) so commonly covering the higher grounds of the Chalk-with-Flints; for they give abundant evidence of the occurrence of that material below Eocene beds, which has only been occasionally noticed elsewhere, and then to a less extent.

For the greater part, so far as I can see, this mass of unworn flints in a loamy or clayey matrix, has been formed here by the dissolving-away of the Chalk beneath the Eocene deposits, leaving behind the practically insoluble flints together with earthy matter, reinforced perhaps from some Tertiary beds. But at what time this process was started one cannot say; it may have been in Eocene times, directly after the deposition of the Blackheath Beds, and it is possible that the dissolution of the Chalk may have begun still earlier. As there is reason to think that the process is still going on, we are faced with a thin mass of material, the formation of which may have been going on slowly and more or less continuously for a long geologic time during which a great thickness of Tertiary beds was laid down.

The Clay-with-Flints therefore seems to be, not a deposit of definite age, but a growth; not part of our stratigraphic series, but the residual product of a condition or state of things that has held, in favourable circumstances, over long periods. As an illustration from another branch of our science, it is in a somewhat like condition to asbestos among minerals, that being, not a definite mineral, but a condition of a certain class of minerals. Nature sometimes declines to be definite.

Occurrences of a like nature are to be expected with other limestones than the Chalk. The most notable case known to me is that of certain manganese-ores in the United States, which occur in huge pipes and pockets in Silurian limestone. Unfortunately I have lost the reference to them.

It is interesting that the black coating so commonly found on the flints in the outer part of the pipes of Clay-with-Flints is due to manganese, and that Mr. G. M. Davies, who has kindly examined specimens of the clays from Worms Heath, taken on a joint visit in October 1918, finds that the grey clay which forms the lining of the pipes owes its colour to a small amount of an oxide of manganese. I had given a short note of his conclusions, but since I wrote it he has written a full account of the matter, which follows.

The few small green-coated flints found are, of course, suggestive of the former presence of the base-bed of the Thanet Sand, while a small mass of bright mottled clay, seen in the pit many years ago, suggests the occurrence of a small included mass of the Reading Beds among the pebbles.

The evidence here therefore, as elsewhere, points to the Clay-with-Flints being a residual product of the dissolution of the Chalk, reinforced by material from the old Tertiary beds.

## VII. Petrological Examination of the Deposits. With Chemical Analysis by A. Broughton Edge, M.B.E., F.C.S.

The deposits will be described in the order in which they now occur in the pipes: namely, Chalk, Grey Clay-with-Flints, Red Clay-with-Flints, sand, and pebbles, although that is not the order of age. The occurrence of halloysite will then be dealt with, and, in conclusion, the mode of origin and subsequent history of the deposits will be considered.

### Chalk.

The chalk belongs to the zone of *Micraster cor-testudinarium*, and contains flint-nodules scattered in moderate amount along the bedding-planes.

In places the chalk is abnormally hard, apparently through deposition in its pore-spaces of carbonate of lime dissolved from higher layers of chalk. Thin sections of this hard chalk show no recrystallization of calcite or other peculiarities of texture. A sample treated with dilute hydrochloric acid gave a residue of 0·99 per cent. brown clay, and 0·011 per cent. coarser material, the latter being chiefly quartz with a little flint, silicified foraminifera, ferruginous matter, etc. A feature observed in rubbing down the sections was the number of dendritic patches of manganese oxide, about 0·5 mm. in diameter, scattered through the chalk and not concentrated along the joints as is often the case. They appear to represent primary segregations of the manganese diffused through the Chalk ooze, and originally extracted from the sea-water by organisms or derived from basic igneous material.[1]

Adjacent to the pipes, the chalk is often soft and plastic through partial solution. This material is easily washed down, and yields abundant foraminifera, polyzoa, sponge-spicules, ostracods, *Inoceramus* fragments, etc. Minute bones, teeth, and scales of fishes, in brown translucent phosphate of lime, and small phosphatic nodules ($1·0 \times 0·5$ mm.), also occur. Most of the foraminifera and some other fossils are silicified, the delicate tests having been dissolved when not so preserved. The chalk, too, is partly silicified, giving rise to porous masses which resemble the cortex of flints, but without the black interior.

### Grey Clay-with-Flints.

This is a dark-grey clay, almost black when wet, containing numerous unworn Chalk flints. The flints often have black manganese coatings, and occasionally groups of green-coated flints may be seen, representing the remains of a bullhead bed which covered

[1] See J. Murray & A. Renard, '*Challenger* Reports: Deep-Sea Deposits' 1891, pp. 372–78

the Chalk before piping commenced. Small pieces of chalk are present in the clay nearest the wall of the pipe, and the clay often shows lamination parallel to the wall and sometimes slickensides with vertical grooves.

The grey clay between the flints, when washed, yields about 67 per cent. of mud. The coarser part of the residue consists of a few pieces of chalk and flint more or less coated with manganese, a large amount of earthy manganese concretions; prisms and fragments of *Inoceramus*, more or less silicified; bones, teeth, and scales of fishes; small phosphatic concretions; crinoid ossicles and other remains. The sandy portion consists of flints and fine quartz-grains, the latter measuring mostly between 0·15 and 0·25 mm. in diameter. There are also heavy minerals, amounting to about 0·005 per cent., apart from the manganese and phosphatic material: they include ilmenite and opaque white grains (leucoxene in part), zircon, staurolite, tourmaline (purple, green, and blue), rutile, kyanite, hornblende, magnetite, andalusite, and possibly garnet. Where the grey clay was exceptionally thick and black, the phosphatic and calcareous constituents were found to be absent or very scarce.

## Red Clay-with-Flints.

The flints are like those in the grey clay, but show little sign of manganese. Thin sharp splinters and flakes are more common than in the grey clay. They show the original cortex of the flint, and are not formed from pebbles. The clay is red and ferruginous, with occasional small black patches of manganese oxide.

A sample of the clay between the flints gave, on washing, flint splinters, ferruginous matter, etc., on 30-mesh sieve, 12·7 per cent.; sand through 30-mesh sieve, 15·2; mud, 72·1. The sandy residue consists of quartz and flint, with a few silicified foraminifera, sponge-spicules, etc. Iron-oxide is abundant, in spheres about 1 mm. in diameter and larger irregular pieces. Manganese-oxide is less abundant, and neither carbonate nor phosphate of lime was seen.

The heavy residue, freed from iron- and manganese-oxides, amounts to 0·043 per cent. It consists of ilmenite and opaque white grains, zircon, rutile, tourmaline, staurolite, kyanite, andalusite, and magnetite. The heavy minerals, and especially rutile and kyanite, are more abundant than in the grey clay, probably through admixture with the adjacent sand during subsidence into the pipes.

## Sand and Sandstone.

The sand which comes between the red clay-with-flints and the pebbles in the pipes is sometimes pale buff or almost white, but more often is stained by iron to some shade of yellow or red. By further addition of iron-oxide it is, in places, cemented into a

ferruginous sandstone. It is uniformly fine in grain and somewhat loamy, as the following table shows :—

| | *Sand on 90-mesh sieve.* | *Sand through 90-mesh sieve.* | *Mud.* | *Diameter of largest grain.* |
|---|---|---|---|---|
| | per cent. | per cent. | per cent. | mm. |
| Nearly white sand, main workings. | 0·4 | 79·2 | 20·4 | 1·8 |
| Buff sand, do. | 0·4 | 84·4 | 15·2 | 1·3 |
| Buff sand, Nore Hill.................. | 1·7 | 69·0 | 29·3 | 1·4 |
| Yellow sand, main workings ...... | 74·0 | | 26·0 | 0·9 |
| Red sand, do. ...... | 79·6 | | 20·4 | ... |
| Red sandstone, do. ...... | 58·8 | | 41·2* | 1·1 |

* Mud and iron-oxide.

The sand consists mainly of quartz, with some flint and white mica. Felspar is very scarce, though plagioclase and microcline have been seen. No glauconite was observed.

The heavy residue ranges from 0·10 per cent. in the nearly white sand to 0·22 per cent., with an average of 0·15. The variation is mainly due to the presence of ferruginous matter. Apart from this and white opaque grains, the chief heavy minerals are zircon, ilmenite, rutile, kyanite, tourmaline, and staurolite. Small amounts of magnetite and yellow and blue anatase are generally present, and in some cases a few grains of andalusite, brookite, epidote, green spinel, and possibly monazite were seen.

Most of the minerals named occur throughout the Lower London Tertiaries of Surrey and Kent. Anatase, it is true, is unusually plentiful, and brookite, which is a decidedly rare mineral in these counties, was noticed several times; but such sporadic occurrences are of no stratigraphical significance. Garnet, which was not observed in these sands, is usually present in the Thanet Sand, but often absent in the higher beds. The absence of glauconite, too, would be exceptional in the Thanet Sand and in the lower part of the Reading Beds, while it is the usual condition in the Blackheath Beds. The supposed Pliocene sands and pebble-beds, which occupy similar positions at Headley Heath and elsewhere on the Chalk of Surrey, are coarser and carry less flint, more mica, and striking amounts of monazite and andalusite. In mineral composition, therefore, the sand has more affinity with the Blackheath Beds or some of the Reading Beds than with any other formation, and the association with thick masses of pebbles suggests Blackheath Beds rather than Reading. While these deposits were accumulating on the flank of the London Basin, however, it is possible that anything from Thanet Sand to London Clay may have been forming in the deeper and more central part of the basin.

## Pebbles and Conglomerate.

The pebbles consist almost wholly of flint. They are well rounded and more or less graded, and frequently show shallow white depressions where decomposition seems to have begun at the points of contact with other pebbles. Very occasionally a flattened brown pebble of quartzite may be seen, such as occur sparsely among the Blackheath pebbles of the Addington Hills, Hayes Common, and other localities.[1] The space between the pebbles is occupied by smaller, less rounded, or broken stones, and fine loamy sand like that just described. This matrix is generally iron-stained to a vivid red or yellow, except where the iron has been leached out through the reducing action of vegetation.

As in the case of the sand, there is much ferruginous cementation, forming blocks of conglomerate which are used locally for ornamenting gardens, and even carted to Croydon and elsewhere. Some of these blocks are very hard and tough, breaking through the pebbles as often as round them. There seems, however, to be no silicification. Gleaming flakes of mica often lie close to the pebbles, and the quartz-grains sometimes show gleaming surfaces, though secondary growth cannot be shown to have taken place. Some of the pebbles are coated with finely botryoidal black göthite, which may show a purple, blue, or yellow tarnish, or with amorphous limonite. Hollow spheres of ferruginous matter, 0·5 to 1·0 mm. in diameter, are seen in some specimens.

## Halloysite.

A white clay-like material found in the pipes was at first regarded as allophane, although the absence of the characteristic waxy lustre and the low water-content suggested that it was more probably halloysite.[2] Chemical evidence has since confirmed this. It consists of white opaque material, ironstained along cracks, and often full of sand-grains, though pieces free from sand are also present. It appears to occur in the sand in the pipes, sometimes near the junction with the pebbles, sometimes near the Clay-with-Flints, but the association with a green-coated flint partly covered with the material indicates that it may have originated in the Bullhead Bed at the base of the Eocene, which is a well-known horizon for allophane and allied minerals.

The material is traversed by shrinkage-cracks, especially where free from sand, and, although it crumbles and softens when wetted, it does not go down to mud. Thin sections may thus be easily prepared. The warm Canada balsam, however, turns the material red, and other organic media give it red, purple, or blue colours at temperatures below 100° C., while ignition only intensifies the coloration.

[1] Mr. A. L. Leach, F.G.S., has also found in the principal workings at Worms Heath a pebble of dark banded quartzite.

[2] G. M. Davies, 'The Rocks & Minerals of the Croydon Regional Survey Area' Trans. Croydon Nat. Hist. & Sci. Soc. (1915–16) p. 92.

Fragments under the microscope appear opaque white in air. In a suitable medium, such as cedar oil, they rapidly become clear and colourless as the liquid penetrates and drives the air out of the pores. The major air-cavities have the form of anastomosing canals, 7 to 10 microns wide. When slightly iron-stained these canals are readily seen, even when filled with Canada balsam or a similar medium.

The material is quite isotropic and free from strain-shadows, before and after ignition. Its refractive index is very near 1·552 (nitrotoluol), well above 1·542 (oil of cloves), and under 1·560 (dimethylaniline). Thin sections in Canada balsam show a refractive index under $\gamma$ quartz and apparently very near $\alpha$ quartz. After ignition the value falls to about 1·542 or even lower. Allophane has a refractive index of 1·49 (Miers). The hardness is not quite 2, and the specific gravity is 2·44, against 1·85 to 1·89 for allophane (Dana). This was found by floating fragments in dilute bromoform, and determining the density of the liquid by the Westphal balance. The specific gravity after ignition is 2·46 or 2·47.

No other minerals appear to have been formed with the halloysite. When the material and its enclosed and adhering sand-grains were washed and panned, only heavy minerals of the kinds common in the sand were seen: namely, ilmenite, limonite, zircon, tourmaline, staurolite, rutile, kyanite, yellow anatase, and magnetite.

Mr. A. Broughton Edge has made a chemical analysis of this material. The sample examined was very carefully selected by him from material obtained by Dr. J. W. Evans, and the powdered substance was pure white and free from visible iron-stains and sand-grains. His results are set forth in columns I & II below, while analyses of halloysite and allophane are given for comparison in columns III & IV respectively:—

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| $SiO_2$ | 41·88 | 0·6980 | 42·6 | 19·58 |
| $Al_2O_3$ | 36·26 | 0·3555 | 36·4 | 37·30 |
| $Fe_2O_3$ | 0·30 | ... | ... | 0·11 (FeO) |
| MgO | none | ... | ... | ... |
| CaO | 0·23 | 0·0041 | ... | 1·36 |
| $Na_2O$ | trace | ... | ... | ... |
| $K_2O$ | trace | ... | ... | ... |
| $H_2O$, at 100° C. | 7·71 | ... | 7·8 | 20·76 |
| $H_2O$, 100° C. to 250° C. | 0·85 | ... | ... | ... |
| $H_2O$, ignition | 13·06 | 0·7255 | 13·2 | 18·43 |
| $CO_2$ | 0·17 | 0·0038 | ... | 2·44 |
| Totals | 100·46 | | 100·0 | 99·98 |

I. Halloysite, Worms Heath. Analyst, A. B. Edge.
II. Molecular proportions corresponding to I.
III. Halloysite, Angleur (Belgium). Analyst, H. Le Chatelier. Bull. Soc. Franç. Minéral. vol. x (1887) p. 210. Recalculated to include hygroscopic water.
IV. Allophane, Charlton (Kent). Analyst, A. B. Northcote. Phil. Mag. ser. 4, vol. xiii (1857) p. 341.

It will be seen that the material from Worms Heath corresponds very closely in composition with halloysite, and may be represented by the formula $Al_2O_3 . 2SiO_2 . 2H_2O + Aq$. This is the formula of halloysite, while without the water it would serve for kaolinite. Allophane corresponds to the formula $Al_2O_3 . SiO_2 . 5H_2O$, or to $Al_2O_3 . SiO_2 . 6H_2O$. The molecular ratio of silica to alumina in allophane is as 1 : 1, not 2 : 1 as in halloysite and kaolinite, and there is more combined water.

Mr. Edge remarks that the material, when shaken up with water, yields a suspension which readily passes through filter-paper. He thinks that it corresponds to the 'kaolin jelly' of E. Ramann,[1] and may have been washed through the sand as a dilute colloid and held up on reaching the clay which lines the pipes.

## Conclusions.

A study of the materials filling the pipes, and of the exposures at Worms Heath, suggests the following sequence of events. By early Eocene times the Chalk had become consolidated, and most of its silica had segregated to form nodules of flint, while manganese was distributed in the form of small dendritic growths. The *cor-anguinum* and higher zones had been eroded by wave-action, when the Chalk sank far enough beneath the Eocene sea to be protected from further attrition. Solution, however, took place either on the sea-floor or beneath a light deposit of sand, and the residual flints acquired a green coating and formed such a bull-head bed as is usually seen at the junction of the Chalk with the Eocene. It is doubtful whether the green coating can be formed, except in contact with sea-water. Subaërial solution of the Chalk may give rise to black-coated flints, but descending meteoric waters are in general too deficient in potash to form green glauconitic or celadonitic products. The sands at Worms Heath contain no glauconite and very little felspar, and the small amount of muscovite present cannot have yielded much potash.

The Chalk with its bullhead bed was covered in succession by the sand, the pebble-bed, and probably by the London Clay and other Eocene deposits. Then followed emergence and subaërial erosion of the overlying beds. Water from the pyritiferous London Clay may have brought the iron that stained the pebble-beds brilliant shades of red, and that formed the masses of iron-sandstone and conglomerate. Comparatively little of the unaltered buff-coloured sand-and-pebble bed is left.

The formation of pipes of such size and depth must be due to a considerable volume of surface-drainage from the London Clay area, which sank into swallow-holes on reaching the permeable Blackheath pebbles and sands. Passing through these, the water encountered the Chalk and began to dissolve it, leaving behind the insoluble flints and brown clay, and at first also the more robust

[1] 'Bodenkunde' Berlin, 3rd ed. (1911) p. 245.

calcareous fossils, the phosphatic fish-remains and concretions, and the manganese oxide. Later, the calcareous and phosphatic materials were removed in solution, and also the manganese, but the latter was precipitated by the bicarbonate of lime in the water near the chalk walls of the pipes. Thus the grey clay was enriched in manganese at the expense of the red clay.

As the pipes continued to increase in depth and area, the Clay-with-Flints was let down, still in contact with the Chalk surface, while the sand and pebbles filled the central portions of the pipes. This downward movement gave rise to the banding and vertical grooving sometimes seen in the clay, and also to the abundant splinters of flint.

We see at Worms Heath the transition from rotten Chalk containing fossils, through grey Clay-with-Flints containing the same fossils, to the common red Clay-with-Flints from which almost everything soluble has disappeared. There can in this case be no doubt as to the residual character of the Clay-with-Flints, and it is unfortunate that the term cannot be restricted to such deposits as are formed *in situ* by the solution of the Chalk. That was Mr. Whitaker's definition when he introduced the name. A large proportion of the deposits mapped as Clay-with-Flints in Surrey, however, indicate a considerable amount of transport and admixture with Tertiary pebbles and clay, Lower Greensand chert and ironstone, etc. The origin of such deposits is not elucidated by the sections at Worms Heath.

## Discussion.

Mr. G. Barrow said that he was interested in the mode of occurrence of the masses of well-rounded flint-pebbles in the Lower London Tertiary Beds. The smallest that he had seen filled channels only some 2 feet broad by 2 feet in depth, yet the stones were of fair size. The difficulty is to know what force drove them along these channels and whence they came, as there is no known source within miles of their present position. From these we have a gradation to masses fully half a mile across, such as that on the Scullet Hill, near Chorley Wood, in Hertfordshire; in this no material other than rounded flints with a black exterior has yet been found. The evidence on the north side of the Thames seemed to suggest that the cutting of these channels began at a certain stage in the Reading Beds; but some of the channels were cut deeper and lasted longer than others. It had occurred to the speaker that the Blackheath pebbles may fill an exceptionally large and deep channel of much the same nature, and possibly started somewhat later. The curious disc-like pebbles of quartzite (such as that exhibited) which so far seemed restricted to the Blackheath Beds were interesting, as the speaker believed them to be composed of sarsen, and they certainly seemed identical with the sarsens proved to be *in situ* in the Reading Beds. Thus a large sarsen was cut across in making the railway at Gerrard's Cross; another was met

with in the Rotherhithe Tunnel. This continued as a sarsen for a considerable distance; later on it contained a few small flint-pebbles, then more and larger pebbles, finally passing into typical Hertfordshire Puddingstone. Small sarsens were also met with *in situ* in the excavations for the Tube railway between the Angel and King's Cross. This suggested that the hollow in which the Blackheath Pebble-Beds had been deposited had been cut after the sand had been silicified into sarsen, the change taking place soon after deposition.

The occurrence of Clay-with-Flints beneath the Blackheath Beds was important. So long as the Bullhead Bed lay at the base of the Reading Beds, no Clay-with-Flints was formed, as the base of the Reading Series contained too much clay to let water pass through. When the base was of a gravelly nature, the clay in the overlying beds was washed down through the gravel, and filled the interspaces between the flints left when the adjacent Chalk was dissolved away.

Sir HENRY HOWORTH said, with reference to the pipes, that it was desirable that their full depth should be ascertained by boring or otherwise. He had never seen a really satisfactory theory of their origin, although the discovery by Mr. Davies of inclusions of manganese, consistent only with a submarine origin, carried us somewhat farther. It was clear, from the evidence given by Mr. Whitaker, that the transport of the pebbles, at all events in the filling of these pipes, took place after the Blackheath Beds were laid down: how much later we were unable to tell. He was of the opinion that the concentric infillings must have been introduced successively, each deposit in turn being however eventually discharged, with the exception of a thin concentric ribbon, which formed a fresh wall to the next comer. He could not see by what process all this was done, nor how pipes more than 30 feet deep could be emptied so methodically more than once.

Mr. A. L. LEACH remarked that the sections at Worms Heath exhibited most interesting effects of solution and subsidence. The curious pittings or hollows noticed on many of the pebbles do not seem to be caused simply by pressure, but by pressure combined with a grinding motion, and the pits are often quite fresh in appearance, as if due to movements recently or still in progress, possibly movements of accommodation to changes of temperature.

The grey discoid quartzites found in the pebble-beds serve to link these deposits with the main area of Blackheath Beds in Northern Kent. Similar quartzites have been found at Charlton, Hayes and Keston Commons, East Wickham, and Bostal Heath. In the last two localities, where they are fairly common, some scores have been collected. They do not appear to resemble either the sarsens found along the North Downs, or any of the sandstones in the Lower Eocene deposits (Woolwich Beds) of Northern Kent.

Mr. WALTER JOHNSON said that he was interested in the revolutionary doctrine which was propounded by Mr. Davies, and might

ultimately be proved correct, to the effect that the Bullhead Bed had not been formed in position, since it required the agency of sea-water to produce the green coat. The suggestion that the London Clay was already being deposited in the deeper parts of the London Basin at the time when the Blackheath pebbles were being heaped up, helped to solve several difficulties. With respect to the pebbles themselves, whence were they directly derived? The older Tertiary deposits could not have afforded enough material, while, contrariwise, the Blackheath Beds may have aided in supplying some of the Bagshot Series: then we must look to the Chalk. It is agreed that the Chalk originally supplied the flinty material; but, in order to gain the present degree of roundness, the pebbles must have travelled a great distance. Patches of the Blackheath Beds are found right up to the Chalk escarpment, and even a little beyond. Could Mr. Whitaker suggest where the Chalk shore-line, during the early stages of the deposition, was approximately situated? The speaker was of the opinion, formed from personal inspection, that the quartzite-pebbles were rather more numerous at Worms Heath than had been allowed for in the paper.

Mr. A. J. Bull said, in regard to the suggested identity of sarsens with the quartzites of the Blackheath Beds, that he had found them to differ petrologically. The grey quartzite consists of quartz-grains with a small amount of siliceous cement, although in places it may be a clear quartz-mosaic; while, in the sarsens, the quartz-grains are separated angular fragments of very variable size, held together by a fine-grained cement or ground-mass which is largely siliceous. The great disparity in the sizes of the grains in the sarsens can readily be detected with a pocket-lens on the fractured surface of a hand-specimen.

Mr. C. E. N. Bromehead expressed interest in the horizontal and vertical distribution of the Blackheath Pebble-Beds. Horizontally they appeared to form a great crescent made up of individual crescentic banks of pebbles, somewhat resembling a series of sand-dunes. The crescents were convex to the east. On this outer side were the marine Oldhaven Beds, on the inner western side the Reading Beds. Immediately in the lee of the crescents the freshwater bed of the Woolwich Series was found, suggesting the formation of freshwater lagoons protected from the sea by the pebble-ridges.

In the vertical sequence he did not think that they marked a definite horizon, but were contemporaneous with various members of the normal Tertiary sequence. At the type-locality the Blackheath Beds occur almost at the base of the Woolwich & Reading Series, only the 'Bottom Bed' being present beneath them, whereas at other points nearly the whole normal sequence was found, and the Pebble-Beds come in at the top; locally, they might even be contemporaneous with the lower part of the London Clay.

The Pebble-Beds in the higher division of the Eocene were similarly impersistent, as, for instance, that at the base of the Barton Sands. At Stanners Hill, between Virginia Water and

Woking, this bed was well developed, and, as mentioned, contained chert-pebbles not found at lower horizons. At St. George's Hill it was practically absent.

A measurement of the total thickness of the London Clay might be made at the Crystal Palace, where, as well as at Shooter's Hill, Claygate Beds occurred, and were described by Mr. Whitaker in 'The Geology of London.' [The thickness is estimated at 380 feet.]

Mr. G. M. Davies, in reply, said that it was not suggested that the pipes were once empty, and were subsequently filled with the various deposits. The sand and pebbles were originally deposited on a more or less level surface of Chalk, and were slowly let down *pari passu* with the solution of the Chalk and the formation of the Clay-with-Flints. He welcomed the facts elicited by the discussion regarding the quartzite and other pebbles in the Blackheath Beds. With regard to the white pittings on the flint-pebbles, he believed that they were due to solution aided by pressure at the points of contact of the pebbles.

## 3. *On the* Occurrence *of* Extensive Deposits *of* High-Level Sands *and* Gravels *resting upon the* Chalk *at* Little Heath *near* Berkhamsted. By Charles Jesse Gilbert, F.G.S. (Read January 22nd, 1919.)

[Plates II & III.]

The deposits hereafter described occur at Little Heath, on the north-east side of the valley of the Bulbourne, near Berkhamsted, at 550 feet above sea-level and in latitude 51° 45′ 45″ N.; longitude 0°·31′ 30″ W. (See D on the map, p. 34.) They rest upon the Chalk of the extensive tableland, which, gradually rising towards the north, culminates at the scarp of the Chiltern Hills. This scarp hereabouts has an average height of about 700 feet, but rises at the Ivinghoe Beacon to 808 feet.

The section to which attention is specially directed occurs in a pit that has been recently opened on Little Heath Common by the Hemel Hempstead Corporation, with the permission of Lord Brownlow, for obtaining supplies of road-metal.

A generalized section of this pit shows the following beds in descending order:—

| | *Thickness in feet.* |
|---|---|
| 6. Surface-soil, with bleached Reading pebbles... about | 2 |
| 5. Pebbly clay and other glacial deposits, varying from | 2 to 20 |
| 4. Stratified loamy sand ............ | 5 to 6 |
| 3. Stratified coarse gravel ............ | 17 |
| 2. Dark clay, with black-coated unworn flints and small well-rounded pebbles ............ | 6 inches |
| 1. Chalk. | |

No. 6. Surface-soil, with bleached Reading pebbles.—This appears to be made up of a portion of the underlying beds, which has become disintegrated.

No. 5. The Glacial deposits.—These are somewhat varied in character. At the top is a pebbly clay, entirely devoid of stratification. The pebbles often exceed the clay in total bulk, and vary usually in size from a pigeon's egg upwards. They are highly waterworn, and appear to have been derived almost exclusively from the Reading Beds. They are nearly all bleached on the surface, suggesting that they were exposed for a considerable time before being incorporated in their present matrix. The bleaching usually extends only for a short distance into the pebbles, but in practically all cases the original black interior has become stained or faded.

In many instances, the characteristic node-rings, due to beach-hammering, have completely disappeared. Sometimes, however, they are more or less preserved, though seldom so clearly as in the

typical Reading pebbles. Where the noding has been lost, the surface of the stone is often so smooth as to suggest ice-polishing.

A very marked feature of this deposit is that the pebbles are almost always in a vertical position, or highly inclined, even when the laminæ of the underlying beds remain horizontal. Occasionally, the flints are found fractured along the vertical line, the two parts remaining in close contact. In other places, the pebbles are crushed *in situ*. This appears to suggest that the beds may have been subject to ice-pressure either after or in process of deposition.

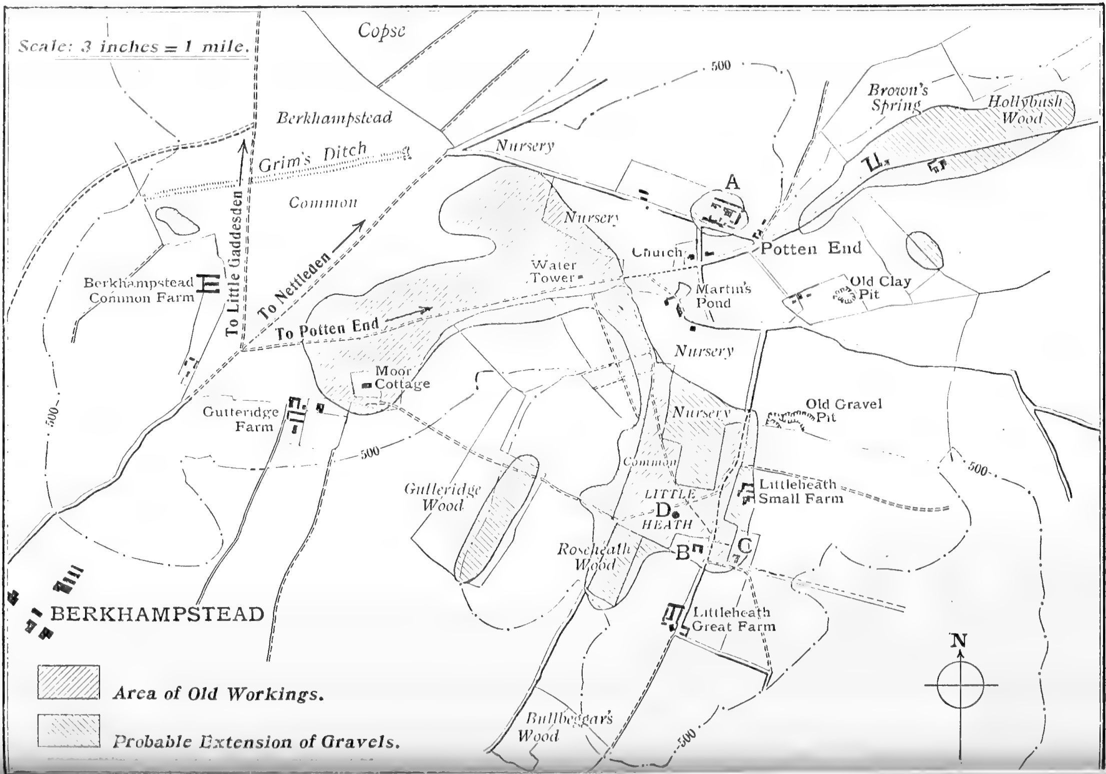
The clay matrix is tough and highly mottled, and varies in tint from very pale grey—almost white—to deep red or reddish purple and brown, the deep colouring being on the whole the more persistent. In the upper portion of the beds the colour is bleached out, and this is also the case where rootlets have penetrated into the clay. In the deeper sections, the dark colouring is more largely retained. At the actual margins of the pebbles the mottling is often very pronounced. It appears probable that the mottled appearance is due to bleaching rather than that there has been an admixture of clays from different sources and of different colours. The tints of the highly-coloured clay leave little room for doubt that it has been derived from the upper part of the Reading Beds.

There is no sharp line of demarcation between these Glacial beds and the underlying loamy sands; in many cases the upper surface of the sands has been cut into, and the beds are intermingled. Indeed, the loamy sands for a foot or so below the junction are usually found to be more or less disturbed.

A singular fact in connexion with these beds is the absence of the Chalk flints which are scattered in such profusion over all parts of the surrounding country, and also the very rare occurrence of the small pebbles of white quartz and lydite, so abundant in the underlying deposits. This appears to suggest that the ice must have derived its materials from an area where these are very rare, and the bleached Reading pebbles abundant. At present, such districts have not been properly and exactly defined, the literature on the distribution of the little quartz-pebbles being very incomplete.

The deposit is extremely persistent over various parts of the Little Heath and Berkhamsted Commons, overlying and often cutting into and disturbing the beds beneath. On the south-west side of the pit, for instance, is a pocket of the Glacial beds, about 12 feet deep, bending down the underlying loamy sands at a high angle at the sides, and at the bottom cutting them out as well as part of the gravel underneath. On the east side another pocket is let in by a superficial fault or landslide, caused by the slipping of the beds into a solution-hollow in the Chalk to about the same depth (see Pl. II). Mr. Whitaker in 'The Geology of London' Mem. Geol. Surv. vol. i (1889) p. 83, refers to these as 'pipes' in the Chalk. In this district they look like large ponds when the gravel or clay has been removed. They are sometimes several hundred feet across, and comparatively shallow, and it is suggested that the term 'solution-hollows' better describes the phenomena.

Map of the neighbourhood of Little Heath, illustrating the occurrence of the High-Level Sands and Gravels.



As this Glacial deposit in the adjacent undisturbed portions of the pit has an average depth of only 2 feet, and in some parts of the Common disappears altogether; and as, in other places, it is found in greater thickness even than in these pockets, it is obvious that it has suffered considerable erosion.

Other Glacial beds.—Underlying the pebbly clay on the west side of the pit is a disturbed mass of sands and clay of a somewhat miscellaneous character. A good deal of the upper part consists of coarse sand with occasional bleached Reading pebbles, showing signs of stratification, side by side with pockets of soft clean sand, probably introduced as frozen erratics. The pebbles are mostly vertical, and some, when removed, are found to have been crushed under pressure. The thickness varies from 4 to 6 feet. Beneath this is an unstratified sandy clay of a dull-grey colour, profusely pitted with black markings. This is from 2 to 4 feet thick, and rests in turn upon a considerable depth of soft, fine, mottled white and brown sands (similar in texture to those above the clay, but showing more persistent signs of stratification), the layers of which dip sharply eastwards. This deposit also contains pebbles with lenticles and patches of mixed material, and altogether suggests an englacial origin (see Pl. III). These lower Glacial beds occur only on the west side of the pit, and are evidently not persistent. At first sight, they appear to be faulted against the stratified loamy sand and gravel, with a clear and almost vertical junction on the south, and a more highly-inclined junction on the north. In reality, however, they form a wedge which has probably been introduced as the result of ice-pressure. The southern fracture can be traced westwards for some distance, thence bending round towards the south-west, and it is from a westerly direction that the pressure apparently came. The vertical junction was traced to a depth of about 20 feet, below which the workings in this part of the pit were discontinued.

At the eastern end of the wedge, the beds against which it had been forced showed signs of considerable disturbance.

We have here no deposits corresponding to the stratified Glacial sands and gravels which are so extensively developed at Bedmond, about 5 miles away to the south-east, and which contain a large percentage of rocks foreign to the district.

No. 4. The stratified loamy sand.—Beneath the Glacial deposits is a well-bedded, dark reddish-brown, mottled, loamy sand, the mottling being due partly to the abstraction of the colouring-matter by root-action, and partly to thin lenticular patches of pale-grey clay or sand. The entire deposit is banded with very fine lines or partings of the grey clay. Some of the partings are built up of thin detached flakes, occasionally rounded at the edges as if by water-action; others are ripple-marked, and others again are covered by sun-cracks and apparent rain-spots, suggesting that each separate layer became exposed to the air after

deposition. The partings are very thin, and in the lower portion of the beds as many as eighteen partings occur in the space of $1\frac{1}{4}$ inches. A careful examination of one section on the north side of the pit reveals these partings distributed as follows, counting from the top:—

| | | |
|---|---|---|
| 1st foot | .................. | 2 partings. |
| 2nd ,, | .................. | 7 ,, |
| 3rd ,, | .................. | 6 ,, |
| 4th ,, | .................. | 6 ,, |
| 5th ,, | .................. | 10 ,, |
| 6th ,, | .................. | 44 ,, |

It will be noticed that the lower section of the sands is more finely laminated than the upper. False-bedded lenticles are sometimes developed; but the lenticles are not cut off at the upper end, as is common with sands deposited by rapid current-action. Isolated flint-pebbles occasionally occur, even in the centre of the bed, up to 3 inches in length, which may have been dashed over the beaches hereafter mentioned, and also thin lenticular patches in which the sand is mixed with very fine quartz- and flint-pebbles, in about equal proportions, with occasional small pebbles of lydite. These patches do not extend more than from 1 to 2 feet.

Very fine particles of white mica are distributed throughout the formation, but never in sufficient quantities to form separate layers. The deposit varies in thickness from about 5 feet on the south side to 6 feet on the north side of the pit. It is all quite compact, and becomes hard on exposure.

Mr. W. Humphrey, of Little Potten End, who worked in these pits for many years, states that in other parts of the Common the loamy sand, when present, has not usually been found in such thickness as in this pit, and that it is sometimes in two or three bands of varying depth; but underneath it, the stratified gravels are always met with.

On the south side of the pit, the beds at first dip slightly westwards, and then suddenly bend down at a high angle in the same direction, letting in the pocket of Glacial beds before mentioned. This is presumably due to ice-pressure, under which the sands have become compressed into a tough band about 18 inches wide. On the north side of the pit, on the contrary, the dip is in the opposite direction, that is, eastwards. This latter variation is probably due to the sinking of the beds into a solution-hollow in the Chalk.

There are two or three minor faults or landslides in the loamy sands and underlying pebble-beds, and on the east side there is the wedge-fault, or landslide already mentioned, along a curved face, bellying westwards, which throws down the Glacial beds and the sands and gravels about 5 feet. (See Pl. II.)

There is almost invariably a sharp break between the loamy sands and the underlying gravel. They do not usually merge one into the other, but are separated by a clear line of demarcation, often with the thin grey lamina right on the junction, suggesting

that the water depositing the sands had a gentle flow. Occasionally, however, the formations merge one into the other, a thin deposit of sand, or sandy loam, being followed by another thin deposit of the gravel. This is probably due to locally-increased tidal action, giving rise to stronger currents.

The underlying gravels at the junction have often an undulating surface, even where the bedding of the sands is horizontal. These undulations are sometimes so pronounced as to suggest the appearance of tidal beaches. The term 'tidal beaches' is used designedly, in contradistinction to the 'storm-beaches' thrown up to such a height as to be placed beyond the reach of further tidal deposits. In the latter case, one would not look for the dense infilling of sand and small pebbles, which is so prominent a feature in the Little Heath deposits. As a case in point, almost the whole of the Dungeness promontory, several square miles in extent, is made up of a succession of huge storm-beaches: the sand-filling is almost totally absent, and will remain so unless and until subsidence takes place. The beaches at Little Heath were on a very much smaller scale, and remained within reach of tidal action by which the infilling was accomplished. No other exposure of the surface of the gravels on any considerable scale is now available for examination; but the evidence of men who have worked in these beds for road-metalling in the past, seems to point to the existence of similar undulations on a larger scale in other parts of the Common.

At the apex of one of the beaches, and at the junction with the loamy sands, a very big pebble weighing several pounds was found resting upon a bank composed, to a considerable depth, of uniformly small pebbles. This occurrence seems suggestive of tidal force.

It may here be stated that the laminæ of the loamy sands in the hollows of the beaches do not always follow the contour-line of the beach, but are deposited more or less horizontally, occasionally with a slight local unconformity. This seems to suggest that the water gained sudden access through one of the beaches, depositing first the heavier burden of sand, and then the lighter of clay in suspension, this operation being repeated by successive storms or high tides, leaving the sands high and dry during the intervals. Hence the sun-cracks. Hence also the variation in thickness and arrangement of the beds referred to by Mr. W. Humphrey, and their entire absence in other places.

The fact that the surface of the clay-partings never shows signs of erosion, either from water or from subaërial agencies, seems to show that the various layers of the sands were deposited at fairly frequent intervals, and that the flow of water was hereabouts very gentle in character. This is what might be expected, on the supposition that the water was tidal, and flowed in from a distance.

No. 3. The stratified coarse gravel.—The coarse material consists almost entirely of Reading pebbles and waterworn flints.

The only other large constituent is an occasional pebble of puddingstone from the Reading Beds, one of which measures 10 inches by 7. Lenticular bands of stratified sand are occasionally met with.

Taken by weight, a considerable part of the deposit, perhaps 40 or 50 per cent., consists of big flints, some as much as 14 inches across. While a number largely retain the outlines of the original form, they are all more or less waterworn, some of them greatly so. Most of these flints, on fracture, are found to have lost their original colouring, as is the case in the high-level gravels met with south of the Thames.

Taken by count and not by weight, the majority consist of typical Reading pebbles, but the nodings caused by beach-hammering, which are so conspicuous a feature of the Reading pebbles, have in many cases been wholly or partly worn off by water-action. As against this, some of the big flints and also the pebbles of puddingstone show distinct evidences of the noding, alike on the fractured faces of the contained flint-pebbles and on the cementing material. This is of considerable importance as an indication of the conditions under which the beds were deposited. While many of the Reading pebbles retain their original colour in contrast with the pebbles in the Glacial beds, quite an appreciable number are bleached. On being fractured, they are usually found to have wholly or partly lost the original dark colouring.

As a general rule, the gravel becomes coarser in depth, the lower sections containing a high percentage of large worn flints. This appears to suggest their deposition during the period of subsidence, especially when taken in conjunction with the presence of the loamy sands above. In no case are the pebbles crushed, as in the Glacial beds. Their long axes usually are nearly horizontal.

The spaces between the pebbles are completely filled with small stones (sometimes packed together) and sand. When the material comes to be sifted for road-metalling through a sieve, it averages about two loads of gravel to one of sand and minute stones. The sand is usually reddish brown, but occasionally yellowish grey. It does not bind, and in this respect differs from the loamy sands above, which are consolidated by a slight admixture of clay. The small stones are mostly Reading pebbles and white quartz, with a few lydite-pebbles. The quartz-pebbles have a polished surface, often stained yellow or orange, and many are semi-translucent. In some cases, nests consisting exclusively of quartz-pebbles are found between the big stones. The number of these quartz-pebbles in the infilling material is very great.

No. 2. Clay, with black-coated unworn flints and small pebbles.—In the bottom of an excavation in the pit, made in order to discover the nature of the basal bed of the gravel, an exposure of the Upper Chalk was reached at 27 feet from the surface. Between the Chalk and the gravel a bed of dark clay was found. It is somewhat greenish in colour, about 6 inches thick, and contains many unworn black-coated flints, broken pieces of

thin tabular flints, numerous Reading pebbles with the typical noding, and small angular pieces of broken flints, the latter usually having a green surface-colouring, probably glauconitic. Also a small number of quite small, smooth, well-rounded, and, occasionally, polished pebbles, and pieces of ferruginous concretions. There are also many fragments of *Inoceramus* washed out of the Chalk, in which the fibrous structure is still retained, but the carbonate of lime has disappeared and has been replaced by silica and apparently some iron-oxide. These fragments of *Inoceramus* are indeed found both in the gravel and in the loamy sand above. Most of the thin flints lie with their long axes parallel to the irregular Chalk surface beneath, and thus give a bedded aspect to the clay, which, indeed, seems to be somewhat laminated.

This deposit rests on the crest of a knob of the Chalk, but on the sloping sides of the Chalk a thin layer of fine sand sometimes intervenes, part of which is white, but mostly red. When the clay is disintegrated it is also found to contain a good deal of sand, a large percentage of the grains of which are stained black.

The feature of the dark clay is its close resemblance to the bed with large unworn flints that over a wide area occurs at the base of the Eocene deposits, whether these be Reading or Thanet, which rest directly upon the Chalk. This Eocene bed is often known as the 'Bullhead,' and it will save useless multiplication of terms if this name is adopted in the present instance.

So far, no contemporaneous fossils have been found in the Little-Heath deposit, but the extent of the exposure which could be examined was extremely small.

A somewhat similar deposit is found at another exposure of the Chalk, which has been excavated at the bottom of an old pit, about 100 yards away to the north-west. This is at a slightly lower altitude, and the pebble-beds here were thinner than in the pit under description.

## General Notes.

It is an important feature in these beds that in the Berkhamsted area they are always found resting directly upon the Chalk. In this respect they differ from all kindred deposits hitherto found north of the Thames, which (where the basal junction has been reached), invariably rest upon the Eocene beds.

Mr. W. Humphrey gives the following further information:—

'The gravel is usually in potholes of the Chalk, though it is often found at the surface lying quite horizontally. It sometimes reaches nearly 30 feet in thickness.'

Each pit has what he calls a 'water-course' at the bottom, which acts as an outlet of the water into the Chalk; and he has sometimes come upon a cavity as big as a wheelbarrow, from which the Chalk has been dissolved. He has never met with a single patch of the brick-earth (altered Reading drift) in any part of Little Heath Common.

The gravel is also found in a field south-west of Little Potten End and over a good part of Berkhamsted Common, at altitudes varying, apparently, by at least 30 feet, the infilling sand and small stones being always present. Where the sand-filling is of a yellow tint, he always expects to find a deeper and richer deposit of gravel. Mr. W. Humphrey's information is largely confirmed from other sources.

At Dwight's cottages at Potten End (see A on the map, p. 34), Mr. J. Matthews (builder) says that he sank 30 feet into loose gravel with sand—similar to the Little-Heath gravel-beds—without finding the bottom, and the cesspit has ever since effectively drained into the gravel.

The gardener of Mr. Norman MacLehose, of Little-Heath House, a short distance from the pit, states that in two excavations in the grounds surrounding the house, they got to the chalk at 18 feet (see B on the map, p. 34). In the water-cistern it was all in the loose gravel (pebble-beds) and kept falling in. In the dumb well about 25 yards away, the pebbles were almost entirely in stiff clay—probably part of the Glacial beds—and just above the Chalk they found four or five cartloads of loose gravel and sand (pebble-beds probably denuded by glacial action).

At Mr. Spencer Holland's (Crossways), about 100 yards away, and about 20 feet lower down the hill (see C on the map, p. 34), Mr. Matthews says that they had to sink 70 feet before Chalk was reached. The upper part for 30 feet was pebbles in clay (Glacial beds). About half-way down, they went through 3 or 4 feet of loamy sands, then the loose gravel (about 35 feet).

## The Origin of the Loamy Sands and Gravels.

That these are marine deposits seems clear from the following considerations:—

(1) The distribution of the pebbles, with those larger and less worn at the bottom, and the tendency to become finer in the upper beds. This quite accords with the behaviour of conglomerates at the base of other and older marine formations (the Cambrian, for instance).

(2) The manner in which the pebbles are arranged in contact one with the other, the interstices packed with small pebbles and sand. This is precisely the structure of modern tidal beaches and the older marine conglomerates, but is not in my experience seen in fluviatile or glacial gravels.

(3) The condition of the large flints, which show a complete gradation from those almost unworn to well-rounded pebbles, similar to the gradation found in beaches in which the materials are immediately derived.

(4) The nodings on the puddingstone pebbles and the worn portions of many of the larger flints, indicative of beach-hammering.

(5) The presence in abundance of small quartz- and lydite-pebbles in the interstices between the bigger stones, which must have drifted along the foreshore for a considerable distance.

(6) The contour and surface undulations of the gravel, so suggestive of tidal beaches.

(7) The occasional big stones thrown to the top and resting on the smaller pebbles at the apex of the beaches at the junction with the loamy sands, suggestive of tidal force.

(8) The construction of the loamy sands in layers, with a period of exposure between each layer, as proved by the ripple-marks, sun-cracks, and rain-pittings, again suggestive of tidal action.

It seems probable that the beds were deposited in a comparatively shallow sea: because, in the deeper waters where the full force of storms can be developed, high storm-beaches will be formed, in which the pebbles are thrown beyond the reach of subsequent tidal action, as at Dungeness, where (as before stated) the storm-beaches have no infilling of sand and small pebbles.

Recent researches appear to indicate that the quartz- and lydite-pebbles in this district have been derived from the Lower Greensand (which crops out north and north-west of the Chiltern Hills), after the final breach of the Chiltern scarp, in the gaps of which the quartz-pebbles are found in great abundance. If this be correct, it would indicate not only that the materials of which the gravel-beds are composed—or, at any rate, a portion of them—came from the north, but also that the vast quantities of the quartz-pebbles which are found everywhere in the upper plateau-gravels nearest to Little Heath are derived from the same source. This is a point of some importance, and one that hitherto has not met with general acceptance.

## The Extent of the Beds.

It may be stated in passing that these beds were mentioned in Prestwich's paper, 'On the Relation of the Westleton Beds...to those of Norfolk' (Q. J. G. S. vol. xlvi, 1890, p. 139), as follows:—

'There is another Tertiary outlier at Little Heath and Potten [Potten End] extending to Berkhampstead Common, or rather, it is a mass of Tertiary strata preserved in a depression in the Chalk [*sic*], of great extent. There is some appearance of Westleton Shingle, but too indistinct for description.'

There is no doubt that he must have referred to the gravels above described, as there are no other deposits in the locality to which his description could apply. It is obvious that Prestwich did not realize the significance and importance of these gravel-deposits, and, so far as can be gathered, the same applies to any other authorities who may have visited the district. Prestwich is quite wrong in saying that they are 'preserved in a depression in the Chalk' as, although it is a fact that they are found in innumerable solution-hollows in the Chalk, which are often on a considerable scale, they also cap the Chalk plateau, lying quite horizontal and undisturbed. The whole of Little Heath Common is dotted with old pits, from which gravel has been removed for road-metalling, although, owing to the abundance of unrolled and well-weathered flints on the hillsides, the pits have for many years ceased working, and have become overgrown with vegetation.

While it is difficult to set an exact limit to the extent of the beds, surface-indications point to their extension in a more or less

continuous sheet from Little Heath as far, at any rate, as Potten End, about half a mile to the north; also, east and west from Little Potten End across Berkhamsted Common, for a distance of at least $1\frac{1}{3}$ miles. The last-named locality is also covered with old gravel-pits.

It is believed that the presence of stratified deposits of sand and gravels of this character at so high an altitude has not hitherto been recorded on the north side of the Thames Valley.

Over a considerable area of Northchurch Common, about $2\frac{1}{2}$ miles north-west of the Berkhamsted deposits, there is an enormous quantity of pebbles, precisely similar in character, and many of them very big, together with worn and unworn flints. These have been worked for many years, but nowhere to any great depth. Whether they are underlain by the stratified gravels *in situ* has not yet been determined; but in any case it seems clear that they cannot have been derived from the Berkhamsted beds on the south-east, and, even if their presence be due to glacial or other agencies, the beds must originally have extended to a considerable distance from the Berkhamsted deposits.

## The Age of the Loamy Sand- and Gravel-Beds.

Pending the discovery of evidence which will finally settle the age of these beds, the following comments are offered:—

That they are not Reading Beds is proved by the fact that they contain well-rounded pebbles of puddingstone, of which several specimens were obtained from different parts of the pebble-beds. The big waterworn and semi-waterworn flints, and the great quantities of white quartz-pebbles which form so large a proportion of the beds, also differentiate them from the typical Reading deposits.

Having then arrived at the fact that they are not of Reading age, we can take a considerable leap forward. The Little Heath beds are at the top and on the upper flanks of the hills, where not only the Reading Beds but the London Clay must have originally been deposited; indeed, there are fragments of the Reading clays and an abundance of Reading pebbles in every direction.

Now, wherever the base of these Little Heath deposits has been reached, they are invariably found to rest directly upon the Chalk without the slightest evidence of intervening Reading Beds. It is obvious therefore—

(*a*) That the London Clay and the Reading Beds had alike been denuded before their deposition.

(*b*) That there is, consequently, a great unconformity between them and the Eocene beds, and

(*c*) That they must be later than the Eocene Beds. They are also Pre-Glacial.

## General Conclusions.

These deposits differ from other kindred deposits north of the Thames, in that they rest directly upon the Chalk. They are found up to at least 560 feet above Ordnance Datum, and extend with practical continuity for at least $1\frac{1}{3}$ miles in length, and in one

EASTERN SIDE OF THE PIT AT LITTLE HEATH.

[On the right are the High-Level Gravels overlain by loamy bands; on the left are the Glacial beds (clay with pebbles) introduced by a superficial fault.]

WESTERN SIDE OF THE PIT AT LITTLE HEATH.

[Gravels on the left; Glacial beds, introduced by a Glacial thrust, on the right: these underlie the clay with pebbles.]

direction for a quarter of a mile in width. They originally covered a much larger area.

They appear to be of marine origin, and to have been deposited as, and in association with, tidal beaches in comparatively shallow water. They were not deposited until the London Clay and Reading Beds alike had been denuded from the area that they cover, and are therefore considerably post-Eocene in age. It may be added that they appear to be uniform with the Pliocene beds south of the Thames, and this, supported by other considerations, suggests that they are of Pliocene age; further, their similarity to the High-Plateau Gravels suggests their contemporaneous deposition also with these gravels.

If this inference be correct, it follows that the High Plateau-Gravels are also of Pliocene age and of marine origin.

They are persistently overlain by Glacial deposits, which have moreover ploughed into and disturbed them throughout the area.

I desire to express my sincere thanks to Mr. George Barrow for the great interest that he has taken in these deposits, and for his valuable assistance throughout my investigations; to Mr. J. F. N. Green, to Mr. W. Humphrey, and to others who have given me the benefit of their experience and the particulars of well-sinkings in the neighbourhood; to Mr. W. R. Locke, the capable Surveyor of the Hemel Hempstead District Council, who has had charge of the workings, and his foreman, Mr. J. Smith, both of whom have assisted me in many ways, and especially in enabling me to obtain a complete section of the beds down to the Chalk. And, finally, to Mr. A. A. Barron and Mr. J. T. Newman for the photographs that have been used in illustration of this paper.

## EXPLANATION OF PLATES II & III.

### Plate II.

Eastern side of the pit at Little Heath. On the right are seen High-Level Gravels overlain by loamy sands. On the left are Glacial beds (clay with pebbles) introduced by a superficial fault. (See pp. 33, 36.) Photograph by Mr. J. T. Newman.

### Plate III.

Western side of the pit at Little Heath. Gravels on the left; Glacial beds, introduced by ice-thrust, on the right. These Glacial beds underlie the clay with pebbles. (See p. 35.) Photograph by Mr. A. A. Barron.

## 4. NOTES *on the* CORRELATION *of the* DEPOSITS *described in* MR. C. J. GILBERT'S *paper with the* HIGH-LEVEL GRAVELS *of the* SOUTH *of* ENGLAND (*or the* LONDON BASIN). By GEORGE BARROW, F.G.S., M.I.M.M. (Read January 22nd, 1919.)

THESE deposits being clearly post-Eocene, the question arises, what is their true age, and with what other similar deposits within or near the London district can they be correlated? Their height above sea-level—550 feet—suggests that they form part of the series of High-Level Gravels, described by various authors under various names, often that of the locality at or near which they occur.

Under the heading of 'Pebble Gravel,' Mr. Whitaker has given a short but good description of these [1] deposits, followed by a list and a brief account of the numerous occurrences of pebble-gravel. Unfortunately, the term has been applied by many of the observers, whose notes he quotes, to deposits that have no connexion with the particular gravels to which he personally restricts the use of this name, so that much of the account is either of no value or misleading. The late Prof. T. McK. Hughes grasped the significance of their extent and mode [2] of occurrence, being especially impressed by their uniform level in the area surveyed by himself in Hertfordshire, a little over 400 feet above sea-level. He called them the 'Gravels of the Upper Plain,' and considered that they must be marine.

On the north side of the Thames, the most extensive spread of these gravels occurs on the Tertiary Ridge, about Stanmore Common, Shenley, Barnet, Potters Bar, etc., and these are taken by Mr. Whitaker as the type occurrences. Recently these occurrences have been re-examined and re-mapped by the officers of the Geological Survey, mostly by Mr. R. W. Pocock, under the supervision of the writer. Brief summaries of the results have been published in the 'Summary of Progress of the Geological Survey.' [3]

These occurrences are especially interesting, and were selected by me in my Presidential Address to the Geologists' Association (1918),[4] as giving the key to the study of the High-Level Gravels on the north and north-west of London, which I believe are of Pliocene age. They illustrate the fact that there are present in this area two distinct types of gravels, other than river-gravels, that contain stones foreign to the district. The best known are the fluvioglacial gravels, which contain abundant pebbles and

[1] Mem. Geol. Surv. 'Geology of London' vol. i (1889) pp. 290–96.
[2] Q. J. G. S. vol. xxiv (1868) pp. 284–85.
[3] Mem. Geol. Surv. 'Summary of Progress for 1913' 1914, pp. 32 *et seqq.*
[4] Proc. Geol. Assoc. vol. xxx (1919) pp. 1–48.

small blocks of foreign material, such as Bunter pebbles (liver-coloured quartzite, etc.), vein-quartz (often in large angular or subangular fragments), Carboniferous Limestone, sandstones of various ages, waterworn fossils (especially *Gryphæa*) from the Lias, Oxford Clay, etc., special types of rock such as Red Chalk and Spilsby Sandstone, many igneous rocks, and in a few localities, fragments of Scandinavian rocks. Now, these foreign components have obviously come from a considerable distance; they are far-travelled.

But the gravels on the Tertiary Ridge, selected as the type of High-Level Gravels, contain no far-travelled material. The chief pebbles foreign to the district consist almost exclusively of small pebbles of white quartz and of lydite; Lower Greensand chert is fairly common in part of the area. These small pebbles have been derived from the Lower Greensand. They can be seen pouring out of the end of water-sieves or screens in operation at Leighton Buzzard, where the incoherent Lower Greensand is sieved for commercial purposes on a considerable scale. There are certain points in these pebbles that help to establish their identity. Many are slightly translucent, and also they have almost a dreikanter form. It is often stated that these Stanmore-Barnet gravels contain quartzite: it is possible that some of the small pebbles from the Lower Greensand may be quartzite, though apparently none have been recorded. The material called 'quartzite,' which is not common, is sarsen, derived from the Reading Beds, and of local origin. Thus, these gravels contain foreign material, often in great quantity, but it is derived from the area beyond the Chalk escarpment, not far removed, but neighbouring, and the pebbles may be described as 'neighbouring.'

Thus there are two types of gravel containing foreign material to be dealt with:—

(1) Those containing far-travelled stones, and

(2) Those containing only 'neighbouring' stones.

In the latter, the local pebbles are nearly all Tertiary, mainly from the Reading Beds; fragments of flint are distinctly uncommon in the Stanmore-Barnet area.

The eastern occurrences on this Tertiary Ridge are all at approximately the same level, a little more than 400 feet above sea-level, and it was to these occurrences that Prof. Hughes referred, when he claimed them as marine. So long as they remain at this level, the quartz-pebbles are abundant, and the associated Reading pebbles are on the whole comparatively small. But, on approaching Stanmore Common, the gravels gradually attain a greater elevation, at one point 500 feet. As the height above sea-level increases, so does the size of the Reading pebbles: thus, when the highest point is reached, these pebbles are, on the average, much bigger than those at Barnet, and many of them still show the original beach-hammering (noding) of the Reading pebbles.

The course of these deposits has been traced from the neighbourhood of London, both on the east and on the west sides of the Misbourne, near Chalfont St. Giles; and at Hampstead Heath they rest upon the Bagshot Beds, while at Barnet and Stanmore they are on the London Clay. Recent work has proved the presence of these beds between Chorley Wood (north-east of Rickmansworth) and the Misbourne valley. At Chorley Wood they rest on the upper part of the brilliantly-coloured marl near the top of the Reading Beds, while farther west, at the Vache, they rest on a slightly lower horizon. It was a little to the north of this that the locality was found where they rested on the 'sarsen' of the Reading Beds. Mr. J. F. N. Green and the writer had the rare good fortune to find a large block of sarsen with the base of these high-level gravels firmly cemented to its upper surface. The gravel here consisted mainly of the typical small white quartz-pebbles. A little farther north the gravel occurs near the base of the Reading Beds, and it was pointed out that these gravels must occur still farther north, resting directly upon the Chalk, but that the outcrops were probably concealed under Drift of some kind.

The gravels of Little Heath, Berkhamsted, described above, are clearly an example of the occurrences predicted; they are typical of the deposits containing the 'neighbouring' small pebbles of white quartz and lydite from the Lower Greensand, but no far-travelled stones. Moreover, the deposit occurring at a higher level, the local stones in the gravel are much bigger than in the area at a lower level and farther south.

It has now been clearly proved that the small quartz-pebbles entered the area about Chorley Wood, and Chalfont, through the Wendover gap, the old floor at 500 feet above sea-level being in part still preserved beneath a thick coating of material mainly composed of large fragments of unworn flint. It is more likely that the quartz-pebbles at Little Heath came either through the gap at the head of the Bulbourne valley (near Tring), or through that at the head of the Gade, probably the former.

A point of especial importance in connexion with these gravels resting on the Chalk, is that the High-Level Gravels north of the Thames are now brought into line with those occurring in a similar position south of the Thames. This leads to the conclusion that these deposits are really allied to the Lenham Beds, but possibly are somewhat younger.

## Discussion on the two foregoing Papers.

Dr. R. L. Sherlock congratulated Mr. Gilbert on bringing before the Society this account of a remarkable section. Mr. Gilbert had devoted much time to a thorough investigation of his subject, and deserved the Society's thanks for a plain statement of facts.

In the five years 1910–1914 the speaker surveyed, on the 6-inch scale, some 300 square miles of the counties of Buckinghamshire

and Hertfordshire, including Mr. Gilbert's district. Owing mainly to the war, that work has not been published, except the very brief abstracts which appear in the Summaries of Progress. There exists in manuscript, however, a complete new survey of the Beaconsfield and Aylesbury sheets, with descriptive memoirs. If those memoirs had been published, Mr. Gilbert would have had the opportunity of criticizing the speaker's account of the deposits at Little Heath.

Mr. Gilbert claims for these deposits an extension of a mile and a half: it is an underestimate, for they are scattered over some hundreds of square miles of the Chiltern plateau. In 1911 the speaker read to the Society a joint paper, by Capt. Noble and himself, on the Glacial origin of the superficial deposits covering that plateau; a paper which caused a warm discussion. Mr. Barrow, among others, opposed the ideas expressed, and it was therefore gratifying to find that he now spoke of the 'Glacial' deposits, as if their age were a matter of common knowledge.

The re-survey was for three years under the superintendence of Clement Reid, and among the occurrences especially looked for were Pliocene deposits. Reid had an unrivalled knowledge of Pliocene beds, and came direct from Cornwall hoping to find a representative of the Pliocene 400-foot platform that he had mapped there. He came to the conclusion that there was no evidence for its existence. Mr. Barrow had seen newer sections, but the speaker would like him to remember that the idea of a 400-foot Pliocene platform had occurred to his predecessors.

The chief point in the papers seemed to be the age of the deposits called Pliocene. No fossils have ever been found. Mr. Barrow seemed to rely mainly on the presence of pebbles of vein-quartz, which (he says) are never found in the Reading Beds of the London Basin. The speaker was not convinced that these quartz-pebbles never occur in Reading Beds, and saw no reason why they should not do so: for, as one proceeds from the Thames Valley towards the Chilterns, there are changes in the character of the Reading Beds: for instance, there appear the Hertfordshire Puddingstone and beds which produce sarsens, and also flint-pebbles that are but partly rounded and sometimes large, instead of the perfectly-formed ones so numerous in, say, the Croydon area. These features indicate that the margin of the deposits is being approached. Good sections may be said to be non-existent; such as occur show signs of disturbance, and so it is open to anyone to say that the pebbles have been introduced later. Quartz-pebbles have been recorded by Mr. Osborne White as extremely abundant in Reading Beds in the Lane End outlier, west of High Wycombe, where he says London Clay caps the deposit, proving it to be in place. He also records lydite-pebbles and subangular flints, which characterize the deposits that Mr. Barrow regards as Pliocene.

It is established that the Reading Beds rest on a plane cut across the gently-folded Chalk. Thus at Taplow, near Maidenhead, Reading Beds rest on the *Marsupites* Zone; farther north, at High

Wycombe and Amersham, they rest on *Micraster-coranguinum* Chalk. Still farther north, there is evidence that the Reading Beds rest on even lower horizons; for example, near Markgatestreet they seem to come down to a little above the Chalk Rock.

The plane on which the Reading Beds rest is the same as the plane regarded as of Pliocene age. This coincidence seemed to the speaker to weigh heavily against Mr. Barrow's conclusion that the plane was cut in Pliocene times.

Mr. H. Dewey objected to the Authors' suggestion that the plateau-gravels of West Surrey were of Pliocene age. The reasons adduced in support of their contention are the presence in those gravels of white quartz-pebbles and the supposed marine origin. As to the mode of origin, it should be remembered that existing conditions of subaërial denudation are forming two plateaux, a higher and a lower one, separated the one from the other by sloping lands. Bagshot Beds form the surface, and are divisible into an upper and a lower series of sands and an intermediate group of clays and loams. The sands form wide flat tracts, heath-covered and often swampy, whereas the clays give rise to gently undulating ground. Precisely similar features occur at the Chobham Ridges, but these great spreads of gravel envelop the underlying solid formations and mould themselves to the pre-existing topography. There is, therefore, no reason to invoke marine erosion when subaërial denudation locally produces similar peneplains.

The Authors infer from the presence of white quartz-pebbles in these, the Chobham Ridge gravels, their origin from the Lower Greensand deposits lying to the north of the Chiltern escarpment; but a more likely source of these quartz-pebbles is surely to be found in the local pebble-beds. Such are found at many localities at the base of the Barton Sands and in the Bagshot Sand, and contain many white quartz-pebbles, although fewer than do the gravels described by the Authors.

When mapping this district for the Geological Survey the speaker came to the conclusion, after weighing all the available evidence, that these gravel-spreads are analogous to the outwash fans of Glacial regions.

He did not, however, consider that the Weald had ever been glaciated, but that its heights had collected on them many years of snowfall, which on thawing liberated torrential floods carrying the frost-splintered rock-débris of the district to the lowlands. The gravels contain up to 50 per cent. of Greensand chert, which must have been brought through the present-day 'dry gap' of the Blackwater. Many large sarsens and blocks of abraded and battered flint are common in the gravels, while the upper beds show contortions and gnarled structures.

Nothing that the speaker had heard that evening had modified the opinions which he had formed and afterwards published in the Windsor & Chertsey Geological Survey Memoir.

Mr. Ll. Treacher suggested that the small quartz-pebbles described by Mr. Barrow, although doubtless ultimately derived

from the Lower Greensand, had also passed through a Reading-Bed stage. Mr. Osborne White (in a paper published in the Proc. Geol. Assoc. vol. xix, 1906, p. 371) had described a section in the Reading Beds at Lane End (Bucks) which yielded these pebbles in abundance, and it was quite possible that from strata of this age once existing farther north but now destroyed, the small quartz-pebbles so common in the Drift-gravels north of the Thames had come. This might also explain the presence of the quartz-pebbles forming part of some sarsens. Sarsens, being portions of the Reading Beds hardened in their original position, would naturally partake of the character of the strata at the spot where the hardening process took place.

Sir Henry Howorth expressed the opinion that Mr. Gilbert's paper contained a large store of facts carefully observed and of inferences. Substantially the paper describes a section on the Chiltern plateau, in which two beds of stratified sand and gravel respectively are overlain by a bed of heterogeneous and unstratified clay with pebbles. In regard to the former beds, he considered that a very good case had been made out for their Middle or late Tertiary age, and for their correlation with similar deposits of similar partly-denuded beds north of the Thames. The absence of fossils is a common occurrence at this horizon; the so-called 'barren sands' of the Red Crag are well known, many stretches of gravel of that date are without shells, and it was difficult to suggest any age for the beds in question other than Tertiary. The speaker had discussed similar beds south of the Thames at some length in his 'Ice & Water,' vol. ii, pp. 159–75. In regard to the unstratified clay-with-pebbles, he objected to the use of the term glacial as applied to this and similar beds. There was not a single glacial feature about them. All the pebbles belong to the locality, and are clearly traceable to the Greensand and to the Reading Beds. There are no travelled stones from the far north and east, and, if they were brought by ice, it must have been local ice; further, there is no adequate gathering-ground for a glacier in this district. There are no angular stones, but all the pebbles are rounded and much weathered, nor are there any scratches on them. Furthermore, a large number of the stones are upright in the beds, showing that they dropped through water by gravitation. It is impossible to conceive their dropping through ice in this fashion, or retaining this position when ice was passing over them. Nor is there any trace of a subglacial stream, but the deposit is clearly a widespread mantle thrown down violently and suddenly, thus accounting for its heterogeneous character. The speaker considered it a pity to qualify the value of observations so interesting by the use of the ambiguous term 'glacial' where its application is so clearly illegitimate. Mr. Barrow had questioned the name of 'quartzite' as given to some of the pebbles, and had suggested that the stones were coloured pebbles from the sarsens. He thought that this was an important suggestion, and one easy of proof.

Mr. R. W. Pocock remarked that, when mapping the gravels of

the Shenley–Barnet ridge, he had found the occurrence of Lower Greensand chert in these gravels to be limited in a north-westerly direction by a fairly well-defined line crossing the area from south-west to north-east. This seems to confirm, to some extent, the view that the gravels came from the south and not from the north, and that they are of earlier date than the Thames Valley.

Mr. Gilbert, in reply, remarked upon the practical absence of criticism upon the essential points of his paper, namely, the origin and the age of the beds. That the gravels were not Glacial was abundantly clear, alike from their composition, uniformity, and situation. Regarding their age, that there was a Pliocene submergence during which certain beds south of London were deposited was beyond dispute. It was highly improbable that such submergence should have failed to reach this district. These beds conformed in every respect to the theory of marine deposition, and linked themselves up naturally with the High-Plateau Gravels and the South London beds. This was all that could be said, as only the discovery of contemporaneous fossils could place the matter beyond controversy. Unfortunately, the nature of the deposits did not afford ground for very confident hope that this evidence would be obtained.

Mr. Barrow, in a brief reply, stated that he quite accepted Mr. Dewey's remarks on the area about Chobham Ridges.

[January 17th, 1920.]

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OF

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[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

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**The Secretaries of the Society are desirous of completing a record of the services rendered by the Fellows in connexion with the War. Details of service, with a statement of rank, regiment, military honours, and any other information, will be gladly received from Fellows, either with reference to themselves or to those known to them.**

C. D. Walcott

**Vol. LXXV.** **No. 298.**
PART 2.



THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY.

EDITED BY

THE PERMANENT SECRETARY.



**[With Six Plates, illustrating Papers by Mr. F. Debenham, Mr. R. H. Worth, and Dr. A. L. Du Toit.]**

APRIL 17th, 1920.

LONDON:

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SESSION 1919–1920.

1920.

| | | |
|---|---|---|
| Wednesday, | April | 21* |
| „ | May | 5 —19* |
| „ | June | 9 —23* |

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

## 5. *A* New Mode *of* Transportation *by* Ice: *the* Raised Marine Muds *of* South Victoria Land (Antarctica). By Frank Debenham, B.A., B.Sc., F.G.S. (Read June 4th, 1919.)

[Plate IV.]

The old and somewhat vexed subject of the methods of transportation of material by land- and sea-ice is again brought up in this paper, a subject on which there is so voluminous a literature that any attempt to add to it must have the support of the strongest reasons. It is, therefore, with some temerity that I attempt the description of a set of facts which appears to contain a key to some of the well-known problems of ice-action.

Of all the phenomena of glacial deposits, perhaps the most puzzling are the occurrences of shelly drifts of marine origin in a great variety of circumstances, both as to height and as to composition. The great discussions of the past as to whether they indicated submergence, or merely an upthrust-action of the ice, can only be said to have been suspended and not concluded.

The subject of this paper is a series of deposits on the Antarctic shores which point to an explanation of the origin of many of these shelly drifts and the peculiar circumstances in which they occur. In South Victoria Land we had the good fortune to see these shelly deposits at an early stage of their evolution, a stage now only possible in polar lands with a severe climate.

The occurrence of raised marine muds, resting upon ice, was reported by the first Expedition that wintered in the Ross Sea, the British National Antarctic Expedition of 1901–1904. They were described by Mr. H. T. Ferrar, the geologist of that expedition, who mentions several deposits of the kind, but does not hazard any explanation. In association with the muds he found deposits of pure sodium sulphate (mirabilite) also resting on ice, which seemed equally inexplicable.

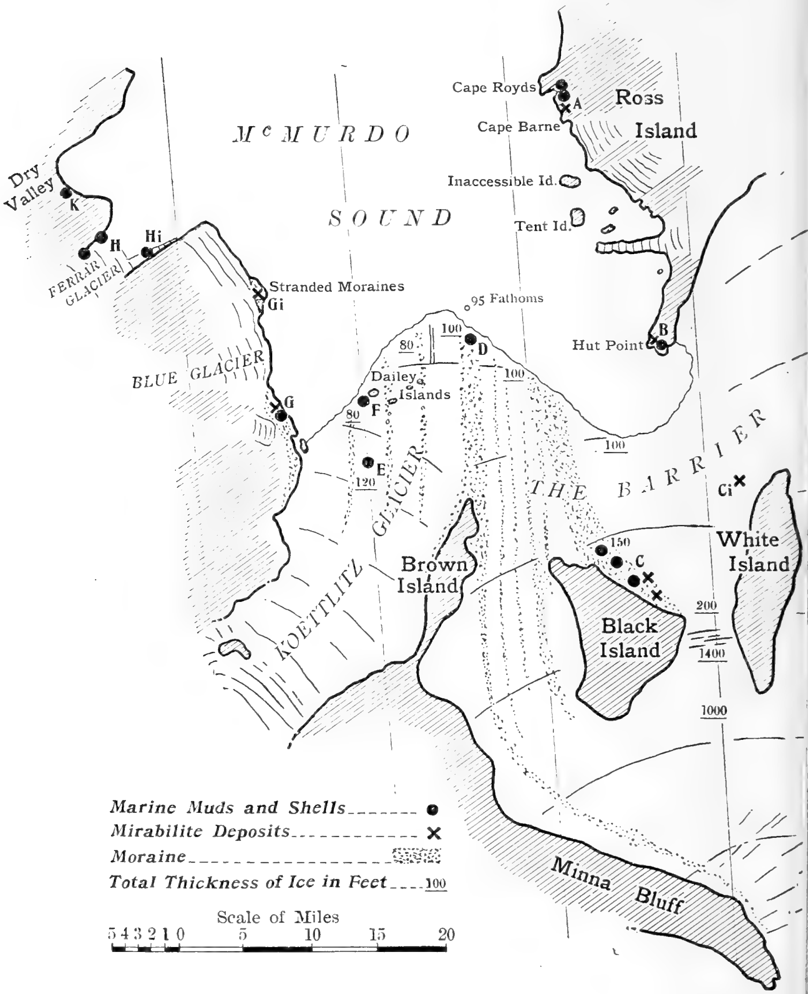
The British Antarctic Expedition of 1907–1909 made important new discoveries of a similar character, and in its geological report a very clear account of them is given together with alternative theories for their mode of origin.

When we of Captain Scott's Last Expedition in our turn made new discoveries of sea-muds and salts on ice the subject assumed a greater importance by virtue of this proof of its widespread occurrence, and it devolved upon me to search for a satisfactory explanation. It must be admitted that such was not found until the end of our stay, too late to verify some of the assumptions that had to be made.

Since any hypothesis on the nature of these deposits will rest largely upon the details of their occurrence in the field, a full

description of the various cases is desirable. The map of McMurdo Sound (below) should be consulted for the exact location of each deposit, remembering that in most cases they rest on slowly-moving ice and are not fixed points. The capital letters in

Fig. 1.—*Map of McMurdo Sound, showing the localities of the raised deposits, moraines, etc.*




parentheses throughout the present paper refer to the positions of the deposits as plotted on this map and on the bird's-eye view of part of the area (fig. 2, p. 54).

The first discoveries are described by Mr. Ferrar in the following words:—

'Among the moraines on the west side of McMurdo Sound (Gi), as well as on one of the Dellbridge Islands (Ai), and among the moraines on the west side of Discovery Gulf (G), great deposits of sodium sulphate in well-formed crystals have been found. Among the isolated moraines in the bay between Black and White Islands (C & Ci) large bosses or mounds of the same white salt have been seen; and at one spot near White Island a mass of perfect crystals was found on the surface of pure ice. In the White-Black Island bay *Balanus* shells and sponge-spicules occurred upon the ice in association with this salt. The occurrence of this salt, mingled with shells and ice-scratched stones, is a freak of Nature which is difficult to explain.' [1]

In a further reference to the matter he describes the mounds above mentioned as five or six in number, 2 feet high and up to 5 feet across. He also mentions a bed of the salt in the moraines on the west side of the Sound as being about 18 inches thick, and traceable horizontally for about 30 feet.[2]

He records the discovery of a *Pecten* shell,

'in gravel 10 miles up the Ferrar Glacier and 20 feet above the sea. The gravel had formed a glacier-table and the ice around was all glacier-ice, but is not above the reach of some exceptional tidal wave' (H).' [3]

On the next expedition to the Ross Sea the geologists, Prof. T. W. Edgeworth David and Mr. R. E. Priestley, found raised marine material in five distinct localities, one of which is outside the region of McMurdo Sound, and is especially important on that account. The latter was discovered by Prof. David on the floating ice north of the Drygalski Glacier-tongue in lat. 75° S. An accurate description of the occurrence is published, together with diagrams which prove it to be quite clearly the exact counterpart of those described from McMurdo Sound.

In brief, it consisted of a bluish-grey clay covering a conical mound of ice to a depth of a few inches, itself covered in parts with large erratic boulders. With the clay and attached to some of the boulders were the marine organisms. They comprised serpulæ, large foraminifera, polyzoa, echinoid spines, and sponge-spicules. To one of the big granite erratics was attached a very large compound sponge, in a state of perfect preservation. The underlying ice was stated to be 'slightly saline superficially, but not as salt as typical sea-ice.' [4]

The organisms were identified by Mr. Hedley & Mr. Chapman as belonging normally to depths up to 100 fathoms, and in general were found to be similar to the collections made by trawling at that depth at the present day. The significance of the exact

[1] 'The Voyage of the *Discovery*' 1901–04, vol. ii, app. i.

[2] National Antarctic Expedition, 1901–04, Natural History, vol. i (Geology) 1907, p. 91.

[3] *Ibid.* p. 79.

[4] British Antarctic Expedition, 1907–9, vol. i (Geology) chapt. xvii.

position of this discovery will be emphasized later when I deal with other instances from this region.

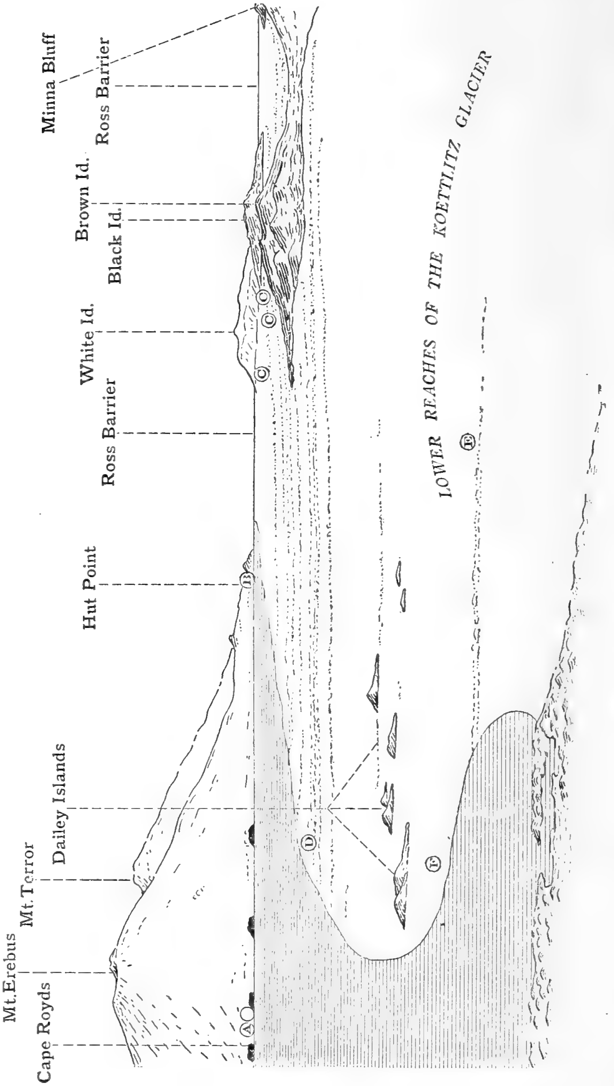
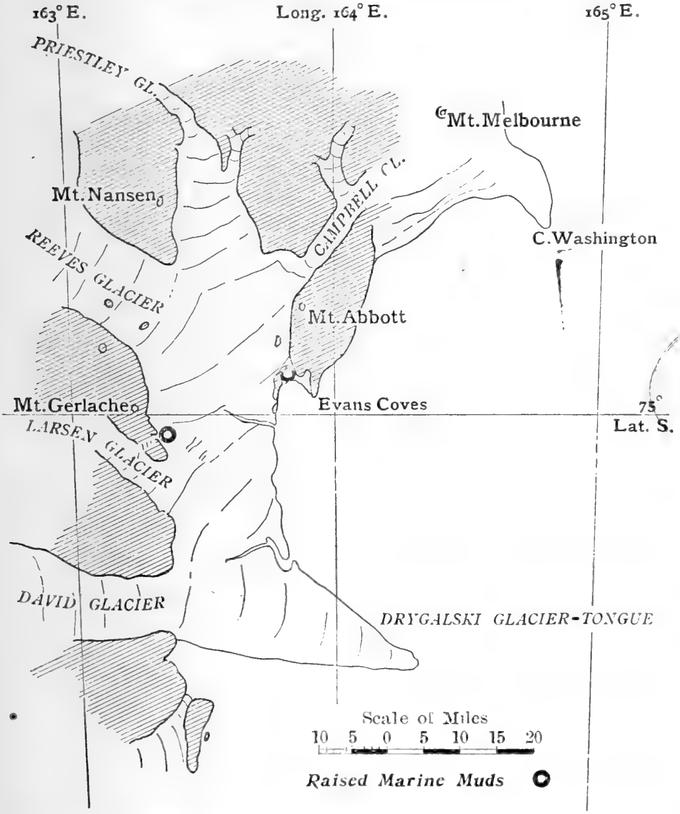



Fig. 2.—*Bird's-eye view of the McMurdo ice-sheet from the foothills of the mainland near G on the map (fig. 1, p. 52).*

An occurrence presenting some variations from the others was discovered by Mr. Priestley at the mouth of Dry Valley (K). It was found some hundreds of yards from the present shore at about 50 feet above sea-level, and consisted of

'a layer of dark gritty sand containing numerous entire valves of *Pecten colbecki* . . . . . associated in abundance with these was an *Anatina* . . . . . Both the pecten and the *Anatina* have extremely fragile shells, yet hundreds of valves, of the pecten especially, were practically intact, . . . . they have a very recent aspect.' [1]

Fig. 3.—*Sketch-map showing the positions of the raised marine muds on the Nansen Sheet.*




[The occurrence near Evans Coves was discovered by Mr. R. E. Priestley, the other by Prof. T. W. E. David.]

It should be noted that this deposit was not resting on ice, differing in that respect from all the other cases.

The three deposits discovered by David & Priestley on Ross Island were visited by me, and will be described later; they proved to be the most important link in the chain of evidence.

[1] Brit. Antarctic Exped. 1907–09, vol. i (Geology) chapt. xvii.

Our own experience of the raised deposits was equally extensive and puzzling. It began with the finding of a new deposit on the very first day that we landed on the west side of the Sound, at the mouth of the Ferrar Glacier (Hi). The south side of this glacier continues beyond the snout proper in a long tongue, which is afloat and carries a good deal of moraine arranged in rough mounds. On some of these mounds were a great many *Pecten* shells with fine silt. No search for other varieties was made, as at that time it was not realized that they were on what may be considered glacier-ice, although it was some 8 feet above the sea-ice proper.

On the next day we visited the north side of the glacier, close to its seaward end (H). At this point the side of the glacier abuts on the steep scree-covered slopes of the hills as a line of high pinnacles of ice covered with a substance which we at first took to be rock-dust blown from the neighbouring heights. Closer investigation showed that it was true mud, and contained numerous fragments of marine organisms. It was resting both on the high pinnacles seen in the photograph (Pl. IV, fig. 1) and on the low mound of moraine in the foreground. The fragments included felted masses of sponge-spicules, valves of *Pecten*, and tubes of *Serpulæ*, and were in great profusion. The tops of the pinnacles were at least 20 feet above the level of the sea. At first, we concluded that the strange position of the muds was due to the pushing-up of the sea-bottom, but began to have doubts about it when we found that many of the shells were of extreme fragility, and, though perfectly fresh, broke readily in the hand. Had we realized then that they represented the fauna of at least 50 or 60 fathoms depth, the 'pushing-up theory' would have received still less support. There is no tide-crack between the end of this glacier and the sea-ice, and the former is probably afloat for as much as 5 miles back from this point, a fact of considerable importance. This deposit must, I think, be correlated with Mr. Ferrar's discovery of a *Pecten* shell '10 miles up the Ferrar Glacier,' for he mentions it as about 20 feet above the level of the sea, and is obviously reckoning his distance from the end of the tongue mentioned above.

The next instance was during our attempts to find a feasible sledge-route up the centre of the Koettlitz Glacier some weeks later, when we came upon abundant evidence of uplifted marine organisms, though not in any definite deposit. The Lower Koettlitz Glacier, like the Lower Ferrar, is afloat at its seaward end, in this case certainly for 7 or 8 miles. Over an area of 3 or 4 square miles in the neighbourhood of the point marked (E) on the map we found an abundance of sponge-spicules on the ice, sometimes in felted masses, but more often scattered singly. These were probably windblown in the majority of cases, coming from deposits of the size that we found later, and the prevalent wind being from the south-east, they must have come from that direction.

Actually at the point (E) another discovery was made which seems to throw some light on the subject. This was the body of

a large fish lying on a patch of silt just beneath the surface of the ice. By careful chopping it was recovered fairly intact, and proved to be about 20 inches long, but without a head. Beneath the skin, which was hardly broken, the body consisted of a mixture of ice and some greasy material, but the bones were quite well preserved. It had certainly never been exposed to the atmosphere for any length of time, or the greasy material would have disappeared. A curious fact about this fish is that in all outward characteristics it was similar to the one captured by the members of the *Discovery* Expedition, also in a headless condition. It further appears to be correlated with their discovery of several skeletons of the same kind of fish in the ice near the point D (fig. 1, p. 52).

The position of this fish embedded in the ice, some 4 miles from the end of the glacier and perhaps 15 feet above sea-level, presents a problem very similar to that of the muds.

It was much too big to be carried by any bird, and would be a very clumsy object to be transported to that distance by a seal, even if seals were known to be in the habit of carrying objects in their mouths. By a stretch of the imagination, it is just possible to suppose that the fish may have worked up some summer-thaw stream to a distance of 4 miles, there to have met its end in the jaws of a wandering seal, who, having eaten the head, left the body to be frozen in. The only alternative, that it came up through the ice from below, seems to me more possible.

On returning from a journey up the Koettlitz Glacier we crossed the Sound to Hut Point on the old ice all the way, the sea-ice having then broken up. At the point (F) about a mile from the westernmost Dailey Island, and a similar distance from the true edge of the land-ice, we came upon the most remarkable instance of uplifted sea-bottom that we had yet seen. The surface here was perfectly level, and probably 8 to 10 feet above sea-level; at this time it was covered with a few inches of recent snow, and our attention was therefore easily caught by two or three small grey mounds on the uniform white expanse. These turned out to be masses of very large sponges, measuring up to a foot in diameter in some cases, and entangled in the masses were the same shells and marine remains as we have already noted in other instances. Again, the most marked feature was the excessive fragility of the bulk of the material. One specimen of a solitary coral was retrieved from a mesh of spicules, and had a peduncle no thicker than a pin, so that it did not long survive the vicissitudes of sledging over the rough ice. The sponges were all in the position of growth, so far as we could see, and there was a small amount of mud and silt with and under them. The mounds were quite close together, as may be seen from the photograph (Pl. IV, fig. 2), but the thick snow effectually prevented us from seeing whether they were continuous or not. This occurrence was most certainly in a position to which no pushing action of the ice could possibly have raised it, and was far too delicate to have withstood any but the gentlest method of transportation.

A few miles farther on, at the head of the rounded cape of floating ice in the middle of the Sound (D), we found that the sponge-spicules were so thickly strewn in the ice that it was impossible to get ice for cooking-purposes that was free of them. There were also fragments of other shelly organisms scattered in the silt of the thaw-water channels. These were for the greater part transported by wind or water, and were much more broken than in the other cases, but they bear testimony to the enormous amount of the material that must be scattered over and in the ice between this point and the volcanic islands south of it.

At Hut Point we found matted tangles of sponge-spicules, as described by Prof. Edgeworth David & Mr. Priestley. The locality is marked (B), but there was no definite deposit, and the specimens were picked up at various points on the low-lying ground. It does not seem likely that these were blown from the direction of White Island, so there is probably a deposit somewhere on the slopes of Observation Hill, similar to those at Cape Royds.

Unfortunately, I was not able to visit the region where there seems to be the greatest extent of the raised deposits, in the bay between Black and White Islands, so nothing can be added to Mr. Ferrar's description of them. I was, however, able to see the occurrences at Cape Royds, in company with Mr. R. E. Priestley, who found them in 1908.

As described in the memoir by David & Priestley, the two deposits of marine muds lie at a height of about 160 feet above the present level of the sea, and consist of a mixture of mud, small fragments of lava, and the usual assortment of *Serpulæ*, polyzoa, etc.

Although the greater part of the shelly material was in small fragments, some of it was very delicate and broke readily in the hand when freed from its matrix. We made a thorough investigation of the deposit at Backdoor Bay, and found that it was resting on ice which was proved to be more than a foot thick, and was perfectly clear and free from bubbles, like old glacier-ice. It may equally well have been sea-ice, from which the salts and the original structure had long since disappeared. Although at so great a height above the sea, these two occurrences fall exactly into line with the others, in that they also are resting on ice.

Besides the new deposits found in McMurdo Sound, an important corroboration of Prof. David's discovery in lat. 75° S. was made by his former colleague, Mr. R. E. Priestley. During their enforced stay at Evans Coves during 1912 our Northern Party made several discoveries of raised marine muds, of which Mr. Priestley has kindly given me the following particulars:—

They were all close to the sea on the surface of the floating ice-sheet which connects Inexpressible Island to the spur of land running south from Mount Abbott. They were about 20 feet above sea-level, and occurred in patches and low mounds, sometimes mixed with big boulders and sometimes by themselves. With

the marine mud were the same organisms as those found elsewhere: shells, sponge-spicules, and polyzoa, generally well preserved, and often in the position of growth that they would have occupied on the sea-floor.

I myself paid a short visit to the locality at a later date, and was able to verify the fact that the ice on which they were resting was similar in character to that of the McMurdo ice-sheet, that is to say, much dissected by thaw-streams. See map (fig. 3, p. 55).

## The Mirabilite-Deposits.

The deposits of sodium sulphate have a peculiar association with those of the raised marine muds and a very similar distribution, as will be seen by the map (fig. 1, p. 52). It therefore appeared to me at an early date that any explanation for one should include the other. A brief description of them is necessary on that account.

The occurrences of the salt found by Mr. Ferrar, as quoted above, were not visited by me; but, from conversation with Dr. E. A. Wilson and others who had seen them, I gained a very clear idea of their nature. Those near White Island were found on mounds of practically clear ice, generally cracked at the top like a pie-crust. It must be pointed out that there is no genetic connexion between the form of the mound and the presence of the salt, except in so far as the association of the salt tends to lower the melting-point of ice and would therefore conduce to thaw. These pie-crust mounds were very common on the Koettlitz Glacier, and are due to the gradual freezing of a small thaw-pool; the expansion of the lower layers as they turn into ice raises the surface-layer into a dome which finally cracks at the top. The deeper the original pool was the higher will be the dome, until it may even assume the form of a crater.

The salt was not bedded in any way in these deposits. Specimens from this locality were analysed by Dr. G. T. Prior, and were found to be practically pure mirabilite, with 55·86 per cent. of water of crystallization.

The deposit of the same salt near Cape Barne (A), which is described by Prof. David & Mr. Priestley, was visited by me at the same time as the marine muds. It occurs near one of the lakes at about 80 feet above sea-level, in a mound some 5 yards long by 2 in width. It is important to note that it is only about 100 yards from one of the shell-deposits, though lower down the hill. The effloresced salt on the surface is so like snow that, except in the summer, it is almost impossible to tell it from the numerous other mounds in the neighbourhood, and we had some difficulty in finding it.

Digging into the mound we came upon the clear hydrated salt immediately below the surface of the dry powdered variety. It was perfectly pure and clear, in blocks up to a foot thick, and, except for the cleavage-planes, might easily be mistaken for ice. In fact, so close was the resemblance that, after digging down

some 4 feet and happening to taste a fragment from that zone, we found that we had passed into true ice without noticing the junction. Careful examination and tasting showed that the salt was only about 2 feet thick at that point, and was resting on perfectly-clear solid ice. It was not bedded, and there was practically no silt with it, although the top of the cone had a slight covering of gravel. It should be remarked that several of the adjacent mounds were also resting upon ice, which could be none other than the original ice of the mass that carried the erratics, the mirabilite, and the marine muds.

The deposit of salt was, therefore, exactly comparable to those found on the moving ice in the bay between Black and White Islands.

The stratified bed of the salt mentioned by Mr. Ferrar in the moraines on the west side of the Sound (Gi) was not found by us; but a very similar one some miles to the south of that point was carefully examined (G). It was in the ice-borne moraine-belt along the coast between Blue Glacier and the Lower Koettlitz Glacier, and was seen from a distance of several hundred yards as a continuous white band in the black moraine. It was cropping out on the side of a small valley which had been thawed out of the underlying ice by a small stream, and appeared as an almost horizontal bed about 2 feet thick, with a definite junction between the bed and the dirt-strewn ice. The moraine itself was of rather fine material, with a proportion of fine mud; the latter, frozen into the matrix of ice, resisted all our attempts at digging a section with a geological hammer. From measurements of the outcrop the deposit appeared to be at least 40 feet long by 20 feet in width. The salt itself was quite free from coarse silt, but contained a small proportion of very fine mud scattered through it, which gave it a dirty appearance. None of it was in clear crystalline blocks as at Cape Royds. On analysis it proves to be almost entirely sodium sulphate, with traces of potassium and of chloride, but the crystal-grains are smaller and more desiccated than in the other cases.

## Summary of Occurrences.

The raised deposits are, therefore, found in two distinct regions in precisely similar circumstances, and it will be worth while to note what other characteristics are common to these regions. It will be convenient to speak of the ice-sheet in 75° lat. S. as the Nansen Sheet, as it is immediately under Mount Nansen, the dominant mass of the neighbourhood.

A glance at the map of South Victoria Land will show that, in sailing southwards along the coast, a ship will pass three deep bays, each of which is filled with thick ice, usually called 'land-ice.' The first of these is Lady Newnes Bay, about which little is known except that the ice that fills it is much more massive than in the other two cases, being up to 150 feet thick at the edge, or, roughly, 1000 feet in total thickness.

About 50 miles farther south another wide bay opens, originally called Terra Nova Bay. Its southern edge is formed by the long floating mass of the Drygalski Glacier-tongue between which and the northern edge is a low sheet of ice formed by the confluence of several glaciers and held in by sundry islands and shallows. This is the Nansen Sheet, and it is probably not more than 200 feet thick, except where the glaciers directly flow into it.

Still sailing southwards along the coast, we meet only with glacier-tongues until the southern end of McMurdo Sound is reached, where a similar sheet formed by the confluence of glaciers blocks the way round Ross Island.

These sheets are all more or less completely afloat, and the two last-mentioned are covered to a great extent with morainic débris. The most important point of similarity is their slow rate of movement—proved in the case of the two where the deposits have been found, and inferred from our small knowledge of the northern one. To regard them as remnants of the Great Ross Barrier is hardly accurate, for (although they are stagnant) they are not wasting very rapidly, and have very definite sources of growth.

The raised deposits all present the following features in common:—

(*a*) In each case they are found resting on ice, with the solitary exception of the one at the mouth of Dry Valley.

(*b*) In each case the organisms appear to have been preserved from shock or movement, and from prolonged atmospheric weathering.

(*c*) The organisms in many cases are preserved in the position of growth, and have been raised without tilting or disruption.

(*d*) They occur at all distances from the edge of the land-ice up to 15 miles.

(*e*) Their height above sea-level varies between 5 and 35 feet, except those at Cape Royds, which approach 200 feet in altitude.

## Theories as to the Mode of Origin of the Deposits.

The only serious attempt at an explanation of these phenomena hitherto made is that given by Prof. David & Mr. Priestley in the Geological Memoir of the 1907 Expedition. In that closely-reasoned account they make the best possible use of the evidence then at hand, and finally discard the theory that the deposits are in any sense 'raised beaches,' always excepting the occurrence at Dry Valley, which has features at variance with the others.

The above-named writers then offer alternative theories, with neither of which are they completely satisfied. Comparing the deposit on the Nansen Sheet, below Mount Larsen, with those in Spitsbergen described by Mr. G. W. Lamplugh, they suggest that the sea-floor may have been ploughed up by the ice of the glacier during an accession after a temporary retreat. Undoubtedly the Seftström Glacier in Spitsbergen has done so, though that action does not seem to explain all the shelly moraines of Cora Island. But, in the case of the Mount-Larsen deposit, many miles from the front of the ice, a ploughing action cannot very well be conceived. The difficulty is still further increased by the fact that

the mound of marine mud does not lie in a direct line with either the David or the Larsen glaciers, but somewhat to the side, as in an ice-eddy or 'backwater.'

An ingenious alternative is suggested by Prof. David & Mr. Priestley, which has chiefly in view the explanation of the organisms being in a position of growth. The portion of the ice-sheet covered with moraine is supposed to have become overloaded with englacial boulders, until its mean density exceeded that of water. It would then sink, and for a time could form a temporary sea-floor for the lodgment of the muds on its surface. The chief objection to such an hypothesis is that, in order to increase the density of ice to that extent, the proportion of included rock would have to be about 1 : 3 throughout the mass, a proportion which is never found in the land-ice of Antarctica.

As the above-mentioned writers point out, to call in any extensive recent elevations or depressions of the land as an explanation is not warranted by other evidence. There are some true raised pebble-beaches and terrace-lines along this coast, and there is no doubt that there have been recent upward movements; but they are limited to some 80 feet or so, and in any case would not explain the occurrence of the muds on floating ice.

In their account, Prof. David & Mr. Priestley do not include the mirabilite as among the uplifted deposits, but consider it as a concentration from a saline lake.

A complete explanation of these phenomena is, therefore, still wanting, and in view of the number of these occurrences now known it is desirable that the problem should be solved. Any agent which can reverse the usual order of things and transport material upwards as well as horizontally is well worth studying, and therefore no apology seems necessary for this detailed treatment. In my view the agency at work is no new one, but rather an old one which has been somewhat neglected by modern geologists. The proof of this will lead into an apparent digression at this point, for it is necessary to describe rather fully the ice-conditions of McMurdo Sound, the type area.

As will be seen in the bird's-eye view of the Sound (fig. 2, p. 54), the whole of its southern end is filled with a sheet of ice which may be regarded as the confluence of two streams: the Koettlitz Glacier coming from the south-west, and the Barrier ice from the south-east. Their union north of Brown Island is marked by a vague shear-crack, showing that there is a slight difference in their rates of movement, and their directions of movement are very clearly indicated by the long lines of moraine streaming northwards to end at the sea in a point usually known as the Pinnacle Ice. The thickness of this sheet varies considerably, and the exact figures are difficult to ascertain except at the edges. Those plotted on the map can only be regarded as approximations, being calculated from various pieces of evidence on the basis of a ratio of 6 : 1, ice below water to ice above. The only evidence for the thickness at a distance from the edge is a series of heights taken by aneroid, by

the *Discovery* parties on their journeys in between the islands. These show very clearly that the thickness of the Barrier proper greatly exceeds that of the McMurdo Sheet.

The rate of movement of this sheet has never been measured, but there is no doubt that it is very slow. The Barrier itself, measured some miles south-east of Minna Bluff, is moving at a fast rate, roughly 1 mile in 3 years. Its direction there is north-north-eastward, and its component towards the Sound would be very much less in any case, even if it were not greatly obstructed by the volcanic islands. The eastern half of the sheet must be regarded as an overflow of the Barrier with a direction of movement almost at right angles to that of the parent mass. The western half is also very slow-moving: for, where it abuts against the Dailey Islands, there are practically no pressure-ridges and only very small cracks radiating from the sides.

The whole sheet is, therefore, comparatively thin and stagnant. It is certainly afloat for the greater part, for all the islands are surrounded by tide-cracks, caused by the rise and fall of the ice-mass with the tides. But there may well be portions of it aground, or very nearly aground, without causing any very marked swelling of the surface, and in the neighbourhood of the islands themselves it is naturally aground. At the edges of the ice-sheet it has from 300 to 500 feet of water underneath it.

The sources of supply of ice to this sheet are twofold, as mentioned above, and even the map shows that the supply is not generous. The Koettlitz Glacier is only some 4 miles wide at its point of outflow from the plateau; but it opens out to an average of 15 miles by the time that it reaches the sea opposite Brown Island. If we assume for the moment that the average thickness of the sheet at this point is 300 feet, and that the rate of movement is uniform, then the thickness of the glacier at its outflow must be over 1200 feet, a very high figure. As regards the eastern half of the sheet, the width of the passages through the islands is about 10 miles, and the width of the sheet north of them is at least 20 miles.

The rate of wastage of the sheet is of great importance, and we must look to its surface for evidence on that point.

It is entirely different from that of the Ross Barrier, now so familiar from photographs and descriptions as an enormous plain of an almost level snow-surface, folded and crevassed near the land, but elsewhere unbroken and spotless. Measurements have shown that in the neighbourhood of Minna Bluff it increases by an annual deposit of about 1 foot of compressed snow. A section down to a depth of 10 feet reveals no approach to ice, but only still more tightly-compressed snow. Observations of 'snow-bergs' derived from the Barrier demonstrate that the passage of snow into clear ice is very gradual indeed.

In all these features the McMurdo Sheet presents a complete contrast. West of a line drawn from the eastern corner of Black Island to the north-west the surface is almost completely covered

with débris. The actual moraines appear as lines of mounds and ridges of ice thickly covered with gravel; but in between these lines the ice is full of silt and mud, some of it undoubtedly wind-blown and some of it probably sea-bottom. The effect of this débris is to increase the thaw in the summer to an enormous extent, so that the whole of the sheet is seamed and dissected with thaw-streams and pools. The general appearance of the surface is one of picturesque grandeur, most gratifying to the artist but heart-breaking to the sledger. The physical result of this heavy thaw is of the greatest importance, for it reverses the order of things as found on the Barrier, where there is an annual increase by snowfall, and produces a net decrease or wastage from the surface. It would be useful to present figures to support this significant fact, but the difficulties of measuring thaw (except in very general terms) are obvious, and the only alternative is to quote instances to show its magnitude.

The sledge parties of the *Discovery* Expedition, in travelling between Black and Brown Islands, described the surface in the following terms:—

> 'Seen from a distance it appeared like a tumultuous sea with high crested waves curling towards us. . . . . Long distances had to be done by porterage, and in the thaw season we had sometimes to take off shoes and stockings to cross rapid streams of water 2 and 3 feet deep.'

It must be mentioned, too, that they were never there at the height of the summer, late in January.

Our own experience was no less striking, although we did not see it during the thaw season. On the Lower Koettlitz Glacier we sledged over many miles of ice which consisted entirely of frozen thaw-streams with islands of higher ice in between. Many of these had been 15 feet wide and 2 or 3 feet deep when running. On the north side of the glacier a strong stream was still running under a thin covering of ice, even in the beginning of March, and we traced its course to the sea for a distance of over 20 miles. At the mouth we estimated its rate at 3 knots, and its average cross-section at 8 square feet. In the real thaw season this stream must be worthy of the name of river, and in many places its original bed exceeded 30 feet in width.

A very approximate measure of the rate of wastage may perhaps be gathered from our experience at the northern edge of the same glacier. While marching over apparently level ice there we continually fell through the thin coverings of former streams, the water of which had run away since the superficial freezing, leaving a space of some depth between the original surface and the floor of the stream. The average depth of these 'sledge-traps' over a large area was about 20 inches, and it seems legitimate to regard that as a rough measure of the wastage of a single summer. The proportional area of these 'ghost streams' to the solid ice was about 20 per cent., which would give a total annual wastage of 5 or 6 inches over the whole of this area. Moreover, at this part of the

glacier there is very little silt on the surface of the ice, and the wastage in the true pinnacle-ice must be very much greater.

The main fact, that the sheet is decreasing from above, does not need figures to support it, for it is proved in other ways. The most obvious proof of this is the accumulation of moraine on its surface. Whereas on the Barrier any moraine which is carried down from the land is soon hidden by the annual increase of snow, on the McMurdo Sheet, moraine which appears on the surface at Black Island is still on the surface at the sea-edge hundreds of years later.

In an ordinary valley-glacier, especially in the Antarctic, there is a zone of surface-increase in its upper reaches, where the erratics are buried as soon as they fall on the ice, and a zone of surface-wastage lower down where the erratics appear on the surface again. The same zones can be recognized on the McMurdo Sheet, the zone of deposition (or surface-increase), with no visible moraine, being near Minna Bluff, a zone of equilibrium somewhere south of Black Island, and the zone of wastage with its exposed moraine lying north of that island.

The change from a superficial increase to a decrease within so few miles is rather remarkable, but is amply accounted for by the combined effects of slow movement and silt covering. Further, in consequence of the annual thaw, the surface of the sheet is formed almost entirely of hard ice, instead of the snow which covers and protects the Barrier surface from too great ablation.

The net decrease of the McMurdo Sheet from the top is, therefore, quite established, but it would be useful to reduce it to figures. To do so involves many assumptions which are open to doubt, on account of the absence of definite measurements, but an attempt will be made later to obtain some approximate measure by calculation.

In the meantime we must now consider the remarkable fact that the thickness of the sheet is approximately uniform north of the volcanic islands. It will be noticed, for instance, that the thickness north of Black Island is 150 feet (from aneroid readings), while 15 miles farther north it is still 100 feet. Now, if we assume that the total loss of surface-ice from thaw is 6 inches per annum we should be well within the actual figure. Then, assuming further that the precipitation is the same as on the Barrier, though it is probably less, there would be an annual increase of 12 inches of compressed snow to set against the thaw. If this be taken as the equivalent of 3 inches of dense ice the net decrease from the surface would be about 3 inches, or 1 foot in 4 years. The rate of movement of the mass is another rather uncertain factor on which to base calculation; but, if we assume that it is 50 feet per year, one-thirtieth that of the open Barrier, we should not be far wrong. At that rate the ice at the northern end of Black Island will take some 1500 years to reach the sea, during which time it should lose about 200 feet in thickness.

This being more than its total thickness, we can only infer that

either our figures are very wrong indeed, or that there is addition to the sheet in the only other possible way, by freezing from below.

When we come to examine the possibility of this taking place through so great a thickness we are again met by a lamentable lack of data. The question may be put in this form:—supposing that the ordinary sea-ice were to remain attached to the land for many seasons instead of breaking up and floating away, how thick would it ultimately become? The answer seems to depend entirely on the situation of the ice with regard to sea-currents, as is shown by the few data that are at our disposal.

Off the end of capes, such as at Hut Point, Cape Armitage, and Cape Evans, where the water is shallow and the strength of the current considerable, the ice which had grown to a thickness of 6 or 7 feet during the winter was thawed through again by the sea-water by the end of the summer. On the other hand, in a protected bay like that south of Hut Point the sea-ice does continue to increase during the second year, if it stays in. In 1902 the ice formed in this bay reached a thickness of 10 feet, and stayed in for the summer. By the end of the next summer it had increased to 15 feet, and there is every reason to suppose that if it had still continued to stay in it would ultimately have frozen to the bottom, although this spot is only half a mile from the shallow patch off the cape where the ice is thawed through each summer from below.

The existence of floes of old bay-ice up to 30 feet thick, sometimes met with in the pack in Ross Sea, shows that conduction of heat is considerable through that thickness of ice, even when deeply covered with snow. The governing factors of freezing at these depths would appear to be the conductivity of the sheet itself and the amount of movement in the water underneath it. Comparing the McMurdo Sheet with the Barrier we get these peculiar contrasts: the conduction of the Barrier would be the minimum, on account of its great thickness and the large amount of air included in it; that of the McMurdo Sheet would be the maximum, on account of its comparative thinness, and because it is formed for the greater part of clear ice.

All that we really know of the movements of the water under the Barrier is that there is a constant drift from east to west along its face. In McMurdo Sound, on the other hand, although there is a strong current coming round Cape Armitage and running up the western side of Ross Island, it seems to be very local, and there is nothing to show the existence of a current coming from under the ice-sheet in the middle of the Sound. Icebergs and pack-ice coming down the Sound under the influence of a northerly wind invariably drift back very slowly on the western side and very rapidly on the eastern.

It seems therefore that the conditions for the increase of the sheet from below are favourable enough to warrant our assumption that this is the explanation of the existence of the sheet long after it should have disappeared under the effects of surface thaw.

The case of the Lower Ferrar Glacier is precisely similar. It is afloat, and its movement is very slow; it is subject to excessive thaw, and it is in so deep an inlet that there can be very little movement of the water on which it is resting. The conditions for decrease from above and increase by freezing from below are even more favourable here.

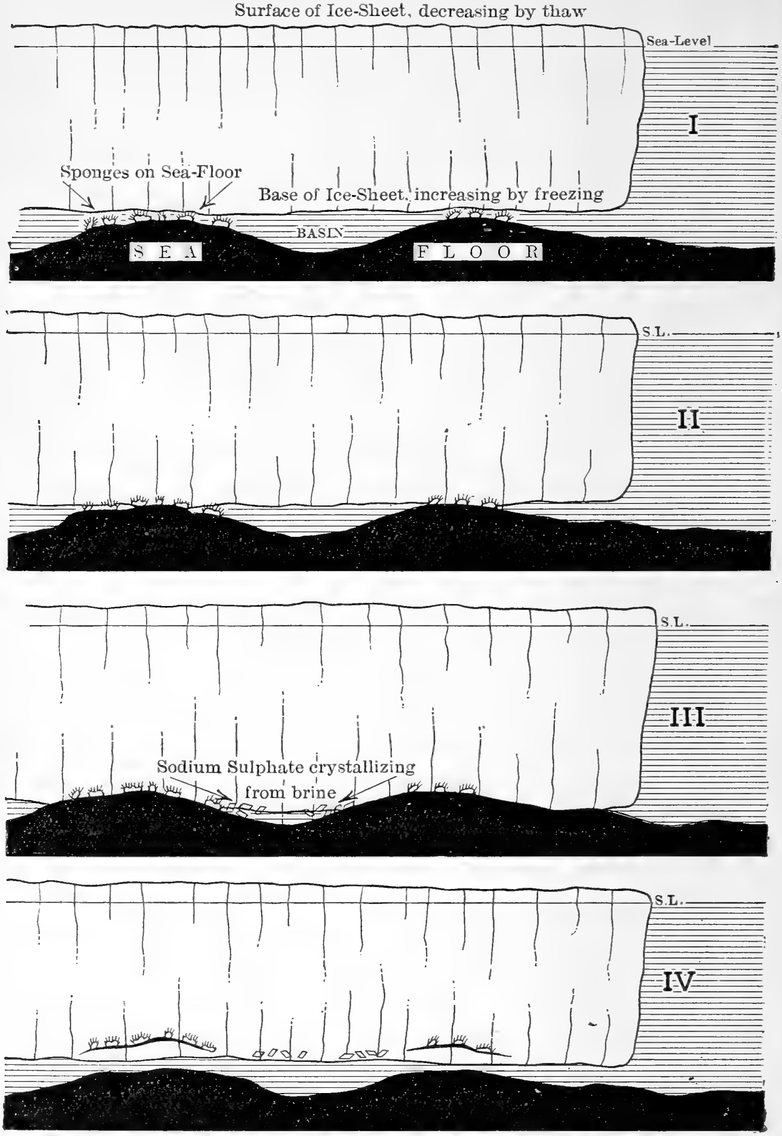
About the Nansen ice-sheet much less is known, but there again the general conditions are favourable. It is sheltered from the coastal currents, and is not very thick. At the points where the raised muds have been found the movement is certainly slow, and the thaw is great.

Probably the freezing on the lower surface of these sheets is not general: for instance, it would not take place close to the sea-edge where the movement of water would be appreciable, or, if it did so during the winter, it would disappear during the next summer. But far under the sheet, where the water is comparatively still, there is probably an annual increase from below which will be inversely proportional to the thickness of the ice and directly proportional to the stagnation of the water.

The origin of the raised marine muds now becomes fairly obvious, and may be described in this way, for the McMurdo Sheet. The overflow from the Barrier moving slowly northwards through the volcanic islands is subject to the two processes, decrease by thaw from above and addition by freezing from below. The rates of both these processes would vary, particularly the thaw, for it is now well known that the weather varies greatly from year to year, and there is possibly a cyclic variation as well. The movements of the ice in a vertical direction would then be of the following nature. A season, or a run of seasons, of heavy thaws and warmer winters would have the effect of decreasing the total thickness of the sheet and lifting it off the bottom wherever it had been touching. On the other hand, a series of colder seasons would thicken the mass, and it would not only rest upon an increased area of the bottom, but would freeze on to some of the muds and enclose them. These would be lifted when next the mass floated at that point, and in the course of many years would finally appear at the upper surface, having been enclosed by ice and therefore perfectly preserved on their way up.

The case of the mirabilite is a little more complicated, but follows from the same conditions. The bottom of the sound, under the ice, is certainly not level, and may be supposed to contain basins. When the ice-sheet rests on the bottom it will enclose a certain amount of water in each of these basins, cutting it off from the rest of the sea. Ice will continue to be deposited from the water, and it will become increasingly concentrated into a brine solution. This happens in all the small lakes on Cape Royds, as mentioned by Prof. David & Mr. Priestley, who found the temperature of the liquid brine residue as low as $-17°$ Fahrenheit. At a certain concentration and temperature the sodium sulphate in the brine would be deposited as solids. The precipitation of this salt from

Fig. 4.—*Diagrammatic representation of the theory.*




I. The ice-sheet afloat.

II. The sheet, having increased by freezing below more than it has lost by thaw from above, now rests upon the sea-floor, freezing-in the sponges.

III. The same at a later stage. The basin has begun to yield sodium sulphate from the brine, some of which is included in the ice.

IV. Milder conditions have caused a net decrease in thickness, the sheet rising off the sea-floor, taking with it the included material.

cooled brine is well known, and occurs in Nature. It takes place in the Great Salt Lake of Utah whenever the temperature of the water falls below about 20° Fahr., and accumulates in such quantities that it can be gathered from the bottom, being a source of the Glauber's salt of commerce.

The ice in the enclosed basin would continue to increase to a small extent, and would enclose a certain proportion of the deposited salt, especially on the borders of the basin. When the ice-mass rose from the bottom again the enclosed salt would be protected from the solvent action of the fresh sea-water which would again fill the basin. Probably a proportion of other salts would be entangled in the sulphate as first deposited, some of which would drain out of it in the course of time, just as in the case of surface sea-ice. The more or less impure mirabilite would gradually rise through the ice precisely as the muds do, but on reaching the surface would probably undergo a further purification in a way that does not concern the subject of this paper.

If we now apply this theory of the origin of the raised deposits, we are able to recognize them at various stages of their evolution from sea-bottom to high-level drift. The first stage is represented by the occurrences of both salt and marine muds immediately north of Black Island. The height of the Barrier immediately south of this island and the existence of long crevasses between it and White Island seem to point to the ice-sheet coming over a submerged ridge between the islands. The original site of the muds cannot in that case be farther south than the northern side of the ridge where the ice again begins to float. In fact, such a position would be a very probable one for the process of freezing to the bottom to take place. The muds off the north side of this island may, therefore, be regarded as having only just come to the surface—the first stage.

A little consideration shows us that this point is a particularly good one for making measurements, and finding out a great deal more about the process.

For, if $T$ = the average thickness of the sheet in that area,

$V$ = the annual rate of movement of the sheet,

$E$ = the distance of the exposure from its origin,

and $D$ = the annual decrease of the surface;

then we have the following relationships:

$$\frac{T}{D} = \text{the number of years that it takes to reach the surface,}$$

and $$\frac{E}{V} = \text{the same.}$$

Therefore we have four quantities, any one of which may be found from the other three. Unfortunately, no measurements of accuracy are available, and even the positions of the deposits are only approximate, so that we cannot at present make any

calculations without wide assumptions. If we take assumed figures as near as judgment will go, we obtain interesting results, which are here given as an example rather than as a basis for deduction.

Taking the thickness as 200 feet, the rate of movement as 50 feet per year, and the distance between the submerged ridge and the first exposure of muds as 5 miles, we get the annual decrease of the surface,

$$D = \frac{50 \times 200}{5 \times 5280} = \frac{10}{25} \text{ feet,}$$

that is, about 5 inches a year.

Of these quantities the thickness and the rate of movement would be comparatively easy to measure, and the quantity E not at all impossible.

The next stage is represented by the deposits near D (fig. 1, p. 52), where the muds have travelled many miles on the surface of the sheet, and have become sorted by water so that the organisms are to some extent damaged by exposure to atmospheric weathering. The fate of these muds is to be floated away on small bergs that occasionally break off from here, most of which would melt in more northern latitudes and return the muds to the bottom of the sea.

The high-level deposits at Cape Royds exhibit a further stage, and are particularly interesting as showing that, even when the McMurdo Sheet was much thicker than its present 100 or 200 feet, the same process of picking up sea-floor was going on. I have no doubt that there are other deposits at a still higher level, but the difficulty of finding them is considerable. The remnant of ice upon which they are still resting will disappear in time, and they will come to the final stage as shown by the Dry Valley case (K, fig. 1, p. 52) where the ice has entirely disappeared, and there is nothing left to show the origin of the shells.

With regard to the shells and sponges that form the bulk of the organisms in the muds it is interesting to note that they come from all depths down to 80 or 100 fathoms, the zone of the sponges in particular being in the neighbourhood of 80 fathoms. The best 'catch' of living sponges was made by the ship in 78 fathoms off the mouth of the Ferrar Glacier. Some of the shells belong to shallower depths; but, as they are all collected on the surface of the sheet, they will ultimately be deposited in the same narrow bed of mud. The occurrence of the deeper forms shows that the process can go on even when the thickness of the ice reaches 600 or 700 feet.

## General Summary.

The results may be recapitulated in a few words, as follows.

The raised marine beds and bottom deposits are found in this part of the Antarctic at all stages of their evolution, and, whatever may be the process of their elevation, it is quite certain that they do rise through the ice, and so are preserved from shock and disintegration. The most plausible explanation of the process is that

the sheets decrease from the top and increase from the lower surface, for which the data are not yet sufficient to provide a conclusive proof. Such data would be very easy to obtain by methodical measurements of one or two quantities, and, moreover, such measurements would probably settle the limits of thickness, depth of water, etc. at which freezing from below can take place.

The numerous instances of raised muds already found prove that the vertical transport of material by ice is going on over a wide area and with considerable activity. There is no doubt that only the difficulty of seeing the deposits on snow-covered moraine has prevented the discovery of many more occurrences than have been so far reported.

In short, there is here a process of transport and deposition going on, which in the aggregate must assume large proportions. Owing to the configuration of McMurdo Sound most of the effects of the process are not perpetuated, since the raised muds float away on the ice as it breaks off. If the northern portion of the Sound were partly closed by large islands, we should doubtless find them covered with silt and muds containing shells and mirabilite.

## Conclusions.

The importance of this discovery and the theory that is here offered to account for it does not lie so much in the explanation of these particular deposits in a remote region of the world, as in the analogies which it may afford for the origin of similar deposits elsewhere.

We have seen that the conditions necessary for the process appear to be reducible to two: (1) a high rate of surface-thaw to more than counteract the precipitation and produce clear ice, and (2) a comparatively stagnant body of water under the ice-sheet. These conditions are liable to be found in any sheltered bay or gulf that has high sides to aid in the thaw, conditions which must be present in the North just as in the South.

The maze of sounds and deep gulfs north of North America would therefore be ideal ground for such a process, and I have little doubt that it is going on there. On reading the descriptions of 'raised beaches' from that region, one is much impressed by the constant reference to the wonderful preservation of the material and the peculiar associations of organisms, features that are typical of the raised muds of McMurdo Sound. Laminaria, for instance, have been found at a height of 200 feet with their characteristic smell still recognizable, bivalves with the cartilaginous hinge still perfect, and so on. These deposits appear to have been universally ascribed to recent elevations of the land, and the issue is certainly clouded by unassailable evidence to that effect; but I think that closer investigation will show that the other process has been at work also.

In Spitsbergen, again, the requisite conditions prevail at the

present day. The summer thaw is excessive, and there should be areas in the deep fiords where the circumstances are favourable to the formation of ice on the nether surface of floating glaciers.

On reading the account by Mr. G. W. Lamplugh of the shelly moraines of the Sefström Glacier,[1] I was immediately struck by what seems to me clear evidence of the same process. The description is so precise and so well illustrated that one can picture the occurrence almost as if one had actually seen it. Without so clear an account I could not presume to add to the observations of the author on this wonderful demonstration of the transporting action of ice. Much of the moraine containing the shells was resting upon the ice, and in fact formed roughly-stratified beds within the body of the glacier, a position which could hardly be attained by any pushing action of the ice on the sea-floor, but exactly what would be expected from the freezing process. In a few patches, seen by Sir Aubrey Strahan, the marine material was in its original order, and included in the ice. Again, the evidence of Mr. H. Trevor-Battye, who saw the glacier at its maximum extension, shows that none of the moraine was supra-glacial, nor was any of it pushed over the land in front of the ice. The moraine now exposed is, therefore, all ground-moraine or englacial. The evidence of the shells themselves, and their wonderful preservation, is a further support to the view that much of it has been transported vertically as well as horizontally, by slowly rising through the mass. Mr. Lamplugh's description of the lateral moraines of the Von Post Glacier shows striking similarities with the deposits in the lateral moraines of the Ferrar Glacier, and I am inclined to think that much of the red boulder-clay has been raised from the sea-floor in a similar way. As in the Antarctic cases, a few measurements of the Spitsbergen glaciers made in the light of the above theory should definitely establish the origin of the raised muds, and it is even possible that the necessary data are already available.

With regard to the deposits left by the Great Ice Age it is obvious that the theory, if accepted, will help to explain some of the anomalies observed in Glacial drifts. Since I can claim no close acquaintance with the shelly drifts of the British Isles myself, it would be presumptuous on my part to attempt any close analogies; but it may be useful to hint at the bearing which this theory may have on the problems that have been investigated by so many great geologists in the past.

One of the difficulties of the shelly drifts is the state of preservation of the organisms. In many cases they are broken and ground down, but in others they are perfectly preserved, with epidermis and ligament intact. On the submergence theory, which means that they were exposed to a gradual elevation, this is difficult to explain; while, if the sea-floor had been forcibly pushed up by the ice, the motion would hardly leave the shells unharmed.

[1] Proc. Yorks. Geol. Soc. vol. xvii (1911) pp. 216 *et seqq.*

The presence of thin lenticles of shelly drift intercalated between beds of boulder-clay is another anomaly that is quite easily explained in this way; in fact, the same occurrence is observed at Cape Royds, where the marine muds disappear under a covering of normal moraine in one place.

The association of different forms of shells, rock, sand, and mud-loving species all in the same drift, is naturally explained, for the bottom muds from different places are ultimately all collected on the upper surface and would be laid down together.

The classic shell-beds of Moel Tryfaen defy complete explanation from this very character as well as from their great height above sea-level. Edward Forbes described them as

'a confused mixture of fragments of species from all depths, both littoral and such as invariably live at a depth of many fathoms.... Deep and shallow-water species mingled could at no time have lived together, or have been thrown upon one shore.' [1]

It is quite possible for the ice-sheet to have frozen to different depths at different times and places, the muds from which would finally find the same level on the surface of the sheet and be deposited together. Rearrangement by fluvio-glacial action might then leave them as they now appear. The difficulty of their great height above sea-level (1400 feet) does not appear to me to be necessarily due wholly to elevation since the Glacial Period. The Great Ross Barrier in one place mounts overland to a height of 1200 feet above its normal level close to its seaward edge, and there seems reason to believe that it rises to a height of 1800 feet on its eastern side where it abuts on Edward VII. Land.

But it must be left to those who know the shelly drifts well to apply the theory, and to judge whether the same conditions as those now found in the Antarctic may not be postulated for the sheets of waterborne ice that invaded these islands in the Glacial Period.

## EXPLANATION OF PLATE IV.

Fig. 1. The northern side of the Ferrar Glacier at H (on the map, fig. 1, p. 52). The marine mud is found on the low hillock in the foreground, as well as on the pinnacles behind.

2. Mounds of sponges and polyzoa on the Lower Koettlitz Glacier at F (on the map, fig. 1, p. 52).

## Discussion.

The President (Mr. G. W. Lamplugh), in thanking the Author for his paper, said that it was of peculiar interest in bringing out clearly the extensive scale on which marine material could be taken up from the sea-floor into an ice-sheet. Such material would afterwards necessarily be transported as far as the ice travelled. In the

[1] Mem. Geol. Surv. vol. i (1846) p. 384.

shelly drifts of the Yorkshire coast it was evident that the material of the sea-floor had in some cases been detached and transported in strips and slabs, and the speaker had surmised the possibility of 'anchor-ice' as an agent, but had been unable to find evidence that anchor-ice was formed in sea-water. The idea that a floating glacier might receive continuous additions from below by the freezing of the sea-water at considerable depths was new to him, as he had been accustomed to suppose that the limit of downward freezing under such conditions was soon reached. But, if the Author was right in this respect, his theory offered a simple explanation of the known facts.

Prof. P. F. Kendall said that glacial geologists would be thankful to the Author for furnishing their armoury with a new weapon. It was over forty years since the suggestion was made that the occurrence of marine shells in glacial deposits could be explained without recourse to a marine submergence. Three ways had been indicated by which remains of marine organisms could be uplifted by ice, and the Author had added a fourth. Garwood & Gregory had found in Spitsbergen that the Ivory Glacier, in passing over an upraised sea-floor, had incorporated in its lower layers shells and other objects which, farther down the valley, come out on the surface of the glacier at an altitude of probably 200 feet or more above their place of origin. These writers attributed this to the lessened mobility of the débris-laden basal layers of the ice, which would offer resistance to the flow, and cause the development of a shear that would bring the shells out on the surface of the glacier.

The case of the Sefström Glacier, described by the President in a paper to the Yorkshire Geological Society, seemed to the speaker to indicate the upthrust of subaqueous moraine by the nose of the glacier.

A third method of uplift mentioned by the President was by the formation of anchor-ice. This, the speaker understood, was a common occurrence in the Baltic, and fishermen, when far from land, on the approach of winter watched carefully for the appearance of cakes of ice rising from the bottom to give them warning of the imminence of a general freezing of the sea. Sometimes the warning came too late, and the boats were frozen in, and had to remain until liberated by the spring thaw.

The Author's interesting communication indicated yet another way in which uplift might be effected.

It is not clear how much of the shelly drift of the North of England can be accounted for by each of these explanations. In the Irish-Sea basin, where shells are found up to altitudes of 1200 and 1400 feet, it is significant that, as R. D. Darbishire pointed out, the same suite of shells is found at the highest elevations as in the low grounds; moreover, the fauna is essentially a shallow-water one, and the grouping characteristic of 200 fathoms is nowhere to be found. Again, the shells are of various ages, many of them of Pliocene types, and they often bear striations due to ice-action. A few small patches like those found by the speaker in the Drift

Fig. 1.—*Part of the northern side of the Ferrar Glacier.*

F. D. photo.

[Marine muds are found on the tops of the pinnacles in the foreground.]

Fig. 2.—*Mounds of sponges and polyzoa on the Lower Koettlitz Glacier, at point F on the sketch-map.*

of the Isle of Man and by the President at Flamborough Head appear to be true fragments of contemporaneous sea-bottom.

He congratulated the Author upon the lucidity of his exposition and the ingenuity of his hypothesis.

Mr. T. Crook remarked that the facts brought forward by the Author were extremely interesting to anyone who had tried to understand the means whereby our own high-level shelly gravels had been transported.

The very interesting process outlined by the Author was one in which the time-factor seemed to be important. A sheet of floating ice would have to be very thick indeed to raise englacial muds and gravels by this means to the heights at which they were found in the British Isles. It was difficult to believe that so thick an ice-sheet could renew itself in this way rapidly enough and completely enough to have the desired effect. The speaker therefore asked the Author whether he could give any gravitation data that would enable one to form some idea of the time that would be involved in the renewal of a thick ice-sheet in the suggested way.

The speaker pointed out that overthrust action in ice-movement was a proved factor of much importance (Geol. Mag. 1911, p. 47); and the Author seemed not to have allowed for the possibility of this action as a means of elevation of englacial material within a moving ice-sheet. The operation of thrust-action had been abundantly demonstrated in Greenlandian and other ice-sheets, and it seemed permissible, therefore, to infer that gravel could be elevated by this means. During a phase of recession when melting was in progress, the raised gravel would be left as relics, which would be seen in all stages from englacial débris to stranded patches, much as the Author had described.

Sir Jethro Teall said that, although certain links in the chain of evidence were necessarily wanting, the Author's theory correlated so many of the remarkable facts which had been observed in the neighbourhood of McMurdo Sound—for example, the frequent association of mirabilite with the various organisms—that he was most favourably impressed by it.

The overthrusting theory was doubtless applicable to certain areas, but it did not furnish a satisfactory explanation of the phenomena upon which the Author had laid special stress.

The Author, in reply, said that, with regard to the question raised by the President as to a limiting thickness in the growth of sea-ice by freezing, it must be remembered that the conditions in the open sea are quite different from those in a deep bay, where the water is comparatively stagnant. The formation of anchor-ice is unknown in the Antarctic, and is apparently limited to fresh water moving at a rate sufficient to prevent surface-ice from forming. As it is the result of radiation, anchor-ice could in no case form under a thick sheet, and that convenient explanation of the raised muds is denied to us. Its occurrence in the Baltic, as mentioned by Prof. Kendall, is very interesting, and is perhaps to be correlated with the fact that the Baltic water has a low

salinity, and in many places is much affected by the river-currents. Mr. Crook's plea for the recognition of overthrust planes can hardly apply to floating sheets of this nature, for they are moving over a frictionless plane, and the parts aground are very local. His question as to the time required for the uplift of the muds is susceptible to calculation by a method which is outlined in the paper, and may be put in the following form:—

$$\text{Time of uplift in years} = \frac{\text{Total thickness of sheet.}}{\text{Annual decrease of upper surface.}}$$

$$= \frac{\text{Distance from origin to point of first appearance.}}{\text{Annual rate of movement.}}$$

In conclusion, he thanked those present for their kind reception of his paper.

# 6. *The* Geology *of the* Meldon Valleys *near* Okehampton, *on the* Northern Verge *of* Dartmoor. By Richard Hansford Worth, M.Inst.C.E., F.G.S. (Read November 20th, 1918.)

[Plates V–VIII.]

Contents.



## I. Bibliography and Introduction.


(1) 1839. Sir Henry T. De La Beche, 'Report on the Geology of Cornwall, Devon, & West Somerset' p. 501.

(2) 1888. Sir Jethro J. Harris Teall, 'British Petrography' p. 316.

(3) 1889. Frank Rutley, unpublished report made for commercial purposes.

(4) 1893. C. A. McMahon, 'Some Notes on Dartmoor' Q. J. G. S. vol. xlix, p. 387.

(5) 1894. C. A. McMahon, 'On Rocks of Igneous Origin on Dartmoor' Q. J. G. S. vol. l, p. 350.

(6) 1895. R. N. Worth, 'Notes on the Geology of Okehampton' Trans. Devonshire Assoc. vol. xxvii, p. 306.

(7) 1901. Harford J. Lowe, Trans. Devonshire Assoc. vol. xxxiii, p. 112.

(8) 1912. 'The Geology of Dartmoor' Mem. Geol. Surv. pp. 38, 40, 47.


The area covered by these notes comprises as much of the watershed of the West Okement and the Redaven as lies between the London & South-Western Railway-line on the north and, on the south, the 'Roof of Devon,' the Yes Tor–High Willhays ridge; practically it is yet further restricted, since but brief reference is made to the granite-mass of Dartmoor.

The rivers and brooks within this area have been useful section-cutters in a country where, for many acres, stray boulders on grassland are the only other guides, and their assistance has been more marked since the great flood of August 14th, 1917, which not only swept their beds clear, but tore away from the banks their cover of grass and heather.

Artificially, also, much has been done to reveal the rock-structure. A very extensive quarry is worked by the railway company east of Meldon Viaduct, the face of this quarry being some 600 yards long. Formerly limestone was raised south of the railway, both on the eastern and on the western banks of the West Okement;

but both quarries are now abandoned. During the last eight or nine years stone has been taken from the dyke of the Meldon aplite east and west of the Redaven, and two small quarries in the same rock were opened several years ago on the flank of South Down, while prospecting work has been executed near the old Ice House on Sourton Tors. There is a quarry in the shales by the Vellake, and slight excavations have been made in connexion with three mines, now abandoned.

The opportunities in the field being thus described, it remains to state that my collection of microscope-sections numbers over 270, and that, by the kindness of my friend Dr. E. H. Young of Okehampton, I have been permitted to examine a further six dozen slides. While no exhaustive treatment of the geology of this area is as yet possible, the main features have probably been ascertained.

The map (Pl. VIII) which accompanies this paper has its limitations: the essentials of structure are (I believe) accurately plotted; but complete mapping from surface-indications would be laborious beyond my opportunities. The boundaries of the quarter-sheets of the 6-inch Ordnance Survey are shown on the map, and their numbers given, it being my practice to refer to all localities and specimens by the sheet-number, followed by a numeral.

## II. General Structure of the Area.

The mass of the Dartmoor granite lies to the south-east: its northern boundary is accurately shown where it crosses the Redaven and curves round West Mill Tor, and again where (after sweeping round Shilstone Tor) it crosses the West Okement and flanks Black Tor; between these points, on the slopes of High Willhays and Yes Tor, no detailed survey has been made.

On the north-west the granite is succeeded by a series of shales, the bedding of which is well defined. For a width across the strike of at least two-thirds of a mile the strike is fairly constant, and may be taken as N. $51\frac{1}{2}°$ E., the dip is always north-westwards and varies between 22° and 76°, with a mean of about 50°. This strike is not many degrees out of parallel with a line which, drawn through the summits of Rough Tor, West Mill Tor, and Yes Tor, would if produced pass but 1300 feet south of Black Tor. Near the foot of the Redaven and at the Limestone Quarry on the western bank of the West Okement there is a local deviation in the strike, a deviation accomplished with some degree of regularity; the dip, however, continues to be north-westward or thereabouts.

But at the northern end of the Railway Quarry, for a short space between normal strikes and dips, there are contortions which bring some of the strata into a vertical position and some horizontal, and even cause sharp folds. With this single exception the shales would appear to be tilted against the granite, but otherwise relatively undisturbed.

Planes of weakness have been developed, the surface-traces of which are broadly coincident with the strike, but they frequently

lie counter to the dip. These planes have been more or less successfully invaded by at least three successive series of igneous rocks, the order of which, commencing with the earliest, is as follows:—

(*a*) A felsite with phenocrysts of micropegmatite.
(*b*) A series, hereafter called the 'Dark Igneous.'
(*c*) Granitoid veins, subdivided into
 (1) The Meldon aplite and its associates.
 (2) Fine-grained granites of the ordinary Dartmoor type.

The evidence on which this chronology has been based seems fairly clear. The felsite with micropegmatite phenocrysts occurs as inclusions in the 'dark igneous' rocks. The 'dark igneous' rocks occur as inclusions in the Meldon aplite. The Meldon aplite occurs as veins in the 'dark igneous' rocks. No evidence is available as to the relative age of the Meldon aplite and the granite-veins.

## III. The Shales.

The shales fall clearly into two divisions, the calcareous and the aluminous. These meet without any apparent transition-beds, but without unconformity, on a well-defined boundary, which may be approximately taken as passing immediately south of LXXVI, S.E. 27, on the Redaven; a little north of LXXVI, S.E. 8, by the Flushcombe brook; and between LXXVI, S.E. 9, and LXXVI, S.W. 7, probably rather nearer the latter.

South of this line all the shales are aluminous, and north of it all the shales are calcareous, until the London & South-Western Railway quarry is reached, where an aluminous rock comes in abruptly and again without apparent unconformity.

The limestone has place as one of the upper members of the calcareous series, if the apparent succession is the real succession, which there seems no reason to doubt.

### The Earlier Aluminous Rocks.

Most of the rocks lying above the granite and below the calcareous series are in reality fine-grained impure grits. They lie well within the metamorphic aureole surrounding the granite, and have been subjected not only to the consequent general alteration, but locally to more intense action where the granite- and aplite-veins penetrate them.

Hard by and for some little distance from the granite the shales are red-brown and rather soft. Specimens from LXXVI, S.E. 34, near Moor Brook, may be taken as a type. The rock varies somewhat macroscopically, and of the two sections described [34 *a*, 34 *b*] the former is grey-brown, without any tint of red. All specimens look gritty, and are minutely banded.

No. 34 *a* contains much very pale mica in scales with occasional larger forms, there are small cinnamon-brown tourmalines scattered through the slide, and rutile in grains and minute well-formed

prisms; an olive chlorite and a quartz-mosaic together make up much of the ground-mass, in which the other minerals are evenly distributed.

In 34 *b*, a very pale brown mica is the dominant mineral. Patches of quartz-mosaic are scattered about the slide, tourmaline is rather rare, but rutile is abundant.

Farther from the granite the red coloration is replaced by grey, the rocks become harder and more compact. LXXVI, S.E. 40, from the bed of the western tributary of the Redaven, is a compact grey rock, finely banded and looking much like a very fine grit. The section shows a quartz-mosaic, varying in texture and markedly coarser and freer from other minerals along irregular bands. Interstitially there is much minute, very pale, green mica, which also shows a tendency to banded segregation. There are moderately large (0·24 mm.) irregular grains of an opaque mineral, apparently a titaniferous iron-ore. On using higher powers, some small rutiles and a very few small brown tourmalines are seen.

LXXVI, S.E. 53, is a grey, hard, minutely-banded and irregularly-spotted rock from the bed of the eastern tributary of the Redaven. The general mass is a quartz-mosaic with very pale green mica interstitially developed. The spots are due to networks of a black opaque mineral, probably magnetite, developed between the quartz-grains. Higher magnifications show irregular grains of rutile and a very few small brown tourmalines.

LXXVI, S.E. 62 *b*, from the bed of the Flushcombe Water above Forest Mine, is a pale-buff, very compact rock, which in the field looks somewhat as though it may be a felsite, but faint grey parallel bands can be seen with a lens. The section shows a fine-grained mosaic of irregular interlocked granules, apparently quartz, with interstitial mica in thin and irregular flakes. There is a very little, extremely pale, brown tourmaline, and rutile is scattered through the slide.

In some of these shales, where oxidation has taken place, the banding is well marked by thin layers of brown and grey: for instance, in LXXVI, S.E. 9 *c* & *d*, quarry by the Vellake.

These examples will serve to indicate the general structure of the aluminous shales; but, beyond the effect of the regional metamorphism induced by the granite mass, there is also the local influence of the intrusive aplite- and granite-veins. This is usually confined to the immediate contact.

At LXXVI, S.E. 29 *b*, on the Redaven, a little above the infall of the eastern tributary, the effect of the intrusion of a narrow dyke of Meldon aplite has been to develop much pale red-brown mica and much brown tourmaline in the shale at the actual contact.

At LXXVI, S.E. 52, on the eastern tributary, a similar dyke, possibly an extension of the same, has only developed pale red-brown mica in the shale, and that for a distance of but 1 mm. or thereabouts from the junction.

At LXXVI, S.E. 30 *a*, where an aplite-vein crosses the Redaven

the contact-shale is highly tourmalinized, the mineral being brown-grey with rare blue shades, in small prisms and grains. The ground-mass is cryptocrystalline quartz, with a very little apatite and sphene.

LXXVI, S.E. 31 *a*, another aplite-vein, yields contact-shale with much very pale mica and rather numerous small prisms of pale brown tourmaline.

LXXVI, S.E. 32 *a*. Redaven. The shale at the contact with a granite-dyke is highly micaceous, both white and brown micas being present. Small brown tourmalines, with occasional shades of grey, are frequent. There are many patches of andalusite, mostly granular, but in part prismatic with clearly-defined pink pleochroism. No. 32 *c*, from the contact with a narrow vein immediately north of 32 *a*, contains no andalusite, and much of the brown mica is altered to chlorite.

LXXVI, S.E. 46, in contact with a vein of granite a few inches wide, in the bed of the western tributary of the Redaven. The altered shale is highly micaceous, the mineral varying from colourless to pale brown, and some being altered to chlorite; there are a very few small tourmalines, pleochroic from colourless to deep red-brown, and a little green tourmaline is present. Granular prismatic patches of andalusite. A little rutile.

At LXXVI, S.E. 62, on the Flushcombe, the immediate junction is marked by much pale-brown tourmaline mingled with red-brown mica; beyond this the rock consists of red-brown mica, granular andalusite, and quartz-mosaic, with small stout rutile-prisms regularly distributed.

LXXVI, S.E. 4, bed of the West Okement above Vellake Corner. The shale in contact with a narrow granite-vein is crowded with a pale mica, contains a little tourmaline colourless to rich cinnamon-brown, and a few grains of rutile. There is no andalusite in the shale, but a fair amount in the granite.

LXXVI, S.E. 9, quarry by Vellake, another aplite-vein occurs here, and the contact-slate develops andalusite and pale-grey mica. Rutile is prominent in all the shale from this quarry.

Andalusite is thus the one additional mineral brought in by the intensive action of the dykes and veins; but the mica is increased in quantity and altered in colour, and the tourmaline is usually increased also.

Within the area considered there is no real tourmalinization of the shales on a large scale; an occasional band may be met with, as at LXXVI, S.E. 45 *a*, on the western tributary of the Redaven: these bands are, however, but a few inches wide at the most. Farther east, south-east of Anthony Stile, the shales are extensively tourmalinized.

The constant references to rutile will have been noted: in my experience one feature of metamorphism by intrusive igneous rocks is that the clay-slate needles, if originally present, either disappear or are replaced by much stouter forms.

## The Later Aluminous Rocks.

Reference has been made to the aluminous shale which comes in to the north of the calcareous series, and is to be found in the Railway Quarry. At first sight, this would appear to be again succeeded by calcareous shales, but the distortion at the eastern end of the quarry is possibly the cause of this apparent succession.

The rock in question is blue-grey, almost black, somewhat soft when quarried, but hardening on exposure. It is crowded with chiastolite-laths, which are not very clearly visible on fresh specimens. The transverse sections of these laths frequently show true crosses, with four external re-entrant angles, and are sometimes even more complex. The rock itself is traversed by close-set, parallel, opaque lines, with small transparent 'eyes' set between them; this structure is continued right into the re-entrant angles of the chiastolite, and where, as is frequently the case, the outer skin of the crystal is altered to mica, the mica forms a clear-cut boundary to the cross (see Pl. V, fig. 1: LXXVI, S.E. 57).

This chiastolite-rock is, on the surface, some considerable distance from the granite, rather more than a mile, and the question suggests itself whether the mineral is due to the rock lying within the metamorphic aureole of the granite, or is a feature of contact-metamorphism induced by the veins of 'dark igneous' rock which occur in the same quarry.

## IV. The Calcareous Series.

With few exceptions, the rocks of this series are either porcellanous, calc-flinta, or chert-like. They vary in colour from white to black, and frequently show a well-marked conchoidal fracture.

The exceptions are, in the first place, the Meldon Limestone, and in the second place certain beds which have decomposed into either black or dark purple-brown clays. The purple-brown clays may occur anywhere in the porcellanous series, but rarely form anything approaching continuous sheets. Transition-forms of partly decomposed rock are found, and these make it evident that the whitest of the rocks may yield this decomposition-product. The black clays are found between chert-like beds near the limestone; they appear to form continuous sheets, and are well exposed on the eastern bank of the West Okement, opposite the Limestone Quarry, and close to the compressor-house of the Meldon Valleys Company.

Black chert-like rocks are associated with the limestone, and occur also at Sourton Lime-Quarry, 3 miles away to the south-west. Two other belts of apparently similar rock exist. The one at LXXVI, S.E. 11, on the banks of the Redaven, where a pit has been sunk upon it, and the other as a prominent outcrop at LXXVI, S.E. 26, some 1100 feet or so away to the east.

It was probably the presence of this rock at 11 which led De la Beche to map a second outcrop of the Meldon limestone; it also induced would-be workers of lime to sink the pit, and to

drive a trench some distance to the north in the hope of striking limestone, but without success.

The black rock bordering the Meldon limestone may be found in large quantity in the quarry-waste; it is nearer absolute opacity than any mineral, other than coal or metallic ores, that is known to me, and it has most of the bad qualities that a rock can show as a material for section-cutting.

It is, however, possible to grind small fragments thin enough for examination. The black pigment is then seen to consist of minute irregular grains, either discrete or in somewhat linear aggregates, and marking out an ill-defined striation. The other minerals are colourless (with one exception) and minutely granular: for the greater part their double refraction is about equal to that of quartz, but some very small lath-forms have a rather higher double refraction. These forms can be isolated from the rotten bands intercalated in the strata: they are frequently clouded with the black pigment, the direction of elongation is positive, they have straight extinction, their refraction about equals that of Canada balsam, and their double refraction exceeds that of quartz by a little; boiling hydrochloric acid does not affect them. The exception above referred to is iron pyrites, grains of which may be seen by the naked eye; many more are shown by a lens, and much is microscopic. In minute form the rock contains a great deal of pyrite, which, like the black pigment, in part aggregates in short groups, all of which have their longer axes parallel.

Prolonged ignition of the rock largely discharges the black pigment from the immediate surface, and makes the colour a rusty black in consequence of the alteration of the pyrites. The pigment appears to be carbon.

The rotten bands, spoken of above as clay, are not really clays—their adhesion and plasticity alike are of the slightest. Chemical tests show the presence of a trace of manganese. If the material is boiled in hydrochloric acid, it yields a solution containing iron, a little alumina and lime, and some magnesia.

The sections of black rock above described bear the number LXXVI, S.E. 1 *c*, and the decomposed rock was taken from the eastern bank of the West Okement, opposite the Limestone Quarry.

LXXVI, S.E. 11, on the northern bank of the Redaven, yields a very similar black rock, but of slightly finer texture. This, while near akin to 1 *c*, is not identical. It contains much pyrite in very small form, and some joint-faces have thin linings of pyrite. The rock is less opaque, and sections are much more easily made from it. In section it shows bands of coarse and of fine texture, of narrow width, the succession being—coarse, band of fine 0·8 mm. wide, band of coarse 1·6 mm. wide, band of fine 1·6 mm., thence grading into coarse without any abrupt junction. A striation due to the pigment crosses these bands, passing continuously from one to the other and making an angle of 34° with their direction, a feature difficult to account for.

As distinct from the two rocks last described, which have only

been exposed by quarrying, the next (LXXVI, S.E. 26) forms a prominent outcrop. It is still finer in texture than 11, and quite easy to section. Although it is as dark as the other rocks in hand-specimens, the microscope shows much less pigment, and that in discrete grains. There is an ill-defined wavy banding. The ground-mass appears to be cryptocrystalline quartz; in this are set many rounded grains of a colourless isotropic mineral of high refraction; some of the grains show forms which may well be sections of dodecahedra, their diameters varying from ·07 mm. downward, with rarely a somewhat larger form. Prolonged ignition gives little glassy blebs on the surface, and it is fairly certain these grains are garnet. Pale-brown mica in minute flakes is scattered through the slide, and microscopic discrete grains of iron pyrites are regularly distributed. The resemblance of 26 to 11 and to 1 *c* is obviously more apparent than real. The field-evidence is all against 11 being a repetition of 1 *c* by folding, and 26 is evidently another species of rock.

The more ordinary shales of the calcareous series vary in shade from white to black, with green tints, and rarely brown, locally developed near igneous intrusions. The colours often occur in narrow bands, but are sometimes dappled; the general effect may be judged from the trade name of 'blue rock.'

The conchoidal fracture is frequently masked by an impersistent cleavage parallel to the bedding, and by an irregular fracture across the bedding. In texture the rock is a porcellanite rather than a calc-flinta. Typical examples from the extreme north and south of the belt (as, for instance, from the Limestone Quarry and from near Redaven Mine) differ but little.

The chief mineral in these rocks is undoubtedly wollastonite in small laths and grains: the structure is much better seen in a slide which has been treated with acid, and subsequently stained. There is also a fair amount of quartz in irregularly interlocked grains. Another colourless mineral occurs in small irregular grains, generally somewhat elongated. This has a refractive index higher than quartz and lower than wollastonite, while its birefringence is higher than that of wollastonite. A rare larger form of what appears to be the same mineral is evidently mica. Except in the presence of direct contact with an igneous dyke, mica in clearly recognizable form and tourmaline are alike absent, while rutile is never found even at the contacts; these constitute broad features of distinction from the aluminous series.

All the porcellanites, even the whitest, contain a sufficiency of iron sulphide to yield sulphuretted hydrogen and separated sulphur on treatment with boiling hydrochloric acid. Possibly some of the sulphide is in pyrrhotine. The acid solution, after treatment of the powdered rock, contains a little iron, much lime, and apparently no magnesia.

Under the influence of the main dyke of the Meldon aplite, and to a minor degree at contacts with the smaller dykes, these calcareous shales develop, in places, certain minerals in such quantity as to

constitute mineral-specimens rather than rock-specimens. Two forms of garnet, idocrase, scapolite, wollastonite, and axinite have thus been found.

Garnet, the most striking form, is cinnamon-coloured, clear and transparent; it occurs both massive and in small well-shaped dodecahedra. The garnet is associated with pure white calcite, wollastonite, and green idocrase; when present it usually forms the larger part of the rock.

Dark-grey garnets are also found, in detached crystals set in the altered shale, and confined to certain of the original beds of the rock. The crystals range from 1 to 10 millimetres in diameter, and are very usually surrounded by a thin shell of calcite. The rock in which they occur is always highly charged with carbonate of lime.

The cinnamon-coloured garnet (Quarry I, 64) shows faint anomalous double refraction in zones parallel to the crystal outline; in this slide it is associated with wollastonite and quartz.

The grey garnet (Q.I, 24) exhibits anomalous double refraction by sectors, and is seen to lie in a matrix of carbonate mosaic. The garnet crystals are usually of sharp outline in part only, elsewhere they die away into the ground-mass which invades them. The garnet is itself colourless, the grey shade being caused by dusty-black pigment, somewhat sparsely scattered. Irregular patches of brown garnet occur (Q.I, 77) in the same slide, and are frequently developed as a discontinuous border immediately outside the boundary of the grey crystals (Pl. V, fig. 2).

Idocrase, green, rarely in parts brown, occurs in masses consisting of radiate elongated prisms; with it are associated cinnamon-coloured garnet, calcite, wollastonite, and in places a little pyrite. A fine specimen of idocrase-rock found loose at LXXVI, S.E. 13, shows that this mineral results from the contact-action of one at least of the smaller dykes of Meldon aplite, as well as from that of the main dyke. In section the green mineral exhibits rather frequent partial alteration towards brown shades. Both the garnet and the calcite conform to the figure imposed upon them by the idocrase, and are interstitial minerals, the wollastonite being intergrown with the idocrase. The characteristic zoning is well developed—an especially neat example is presented by Dr. Young's slide 'Y.J. 4' (Pl. V, fig. 3).

Scapolite is in my experience rare. It was found by Dr. J. S. Flett (8, p. 47).[1] The specimens available are almost pure scapolite-rock, in part granular massive, but with silky bundles of prisms of considerable length (up to 30 mm.). An occasional spot of blue apatite is the only other mineral, except for an infiltration of manganese. The section Q.I, 65 presents both square and elongated forms, with small grains and crystals of apatite as inclusions. Cross-sections of the scapolite (dipyre) show a narrow outer zone (Pl. V, fig. 4).

Wollastonite is the commonest of the recognizable products

[1] These numerals in parentheses throughout the paper refer to the Bibliographical List on p. 77.

of alteration. In fibrous form it frequently fills cracks in the shale, the fibres extending from side to side of the crack. Layers 10 mm. and more thick are thus formed, which part readily from the walls of the crack and can be obtained as small slabs. The only other mineral certainly present is pyrite in an occasional grain, but there seems some reason to believe that a little pectolite may also occur. (Very fine specimens of pectolite in radiate form have been found in the L. & S.W. Railway quarry.) Wollastonite also occurs intergrown with idocrase.

Axinite is confined to the immediate neighbourhood of the junction. In colour it is a very light purple-brown, the crystals being clear and transparent. It is associated with dark tourmaline, with fluorspar, and with epidote. Axinite is also found in the rocks north of the Meldon aplite-dyke, by the Redaven; it is there rather dark brown, and its origin may be connected with a vein of the 'dark igneous' rock.

Lepidolite is a mineral of the inclusions rather than of the contact-rocks. The smaller inclusions, the mere broken fragments some few inches in diameter, which have been torn off from the shales and wholly surrounded by the Meldon aplite, in their fullest alteration acquire a horny texture and lustre. They cleave readily, the cleavage-surfaces being curved and waved and having a satiny sheen. The colour is brown-grey, with a slight silvery lustre. The material is translucent. A modification occurs, which is intermediate between this texture and porcellanite. The whole rock fuses readily at the edges of chips in the bunsen burner, and gives a strong lithium flame.

To the naked eye sections appear as practically clear glass, if cut parallel to the cleavage (Q.I, 28): they show no structure under the microscope, except between crossed nicols, but then appear as a rather irregular mosaic of small grains polarizing in grey tints, with occasional blades and grains giving fairly high colours. Omitting for the moment certain subsidiary minerals present in small quantity, the rock is an aggregate of flakes of lepidolite arranged with their cleavages almost uniformly parallel: hence the low tints of the majority of the grains which are viewed normal to the base (Q.I, 28) [Pl. V, fig. 5]. Cross-sections at right angles to the cleavage of the rock show a blade-like form of the grains: the whole section is low in tint between crossed nicols when the direction of cleavage of the rock is parallel to either diagonal, and shows only spots of high colour; but at the 45° position, it takes on high tints, which are uniform over wide belts, and show only a few spots of lower colour (Q.I, 68). Grains of apatite and needles and grains of green tourmaline occur as accessories.

In Q.I, 45, which shows a junction of the Meldon aplite and one of these inclusions, the inclusion farther from the aplite contains an occasional small crystal of green tourmaline; nearer the junction there is much pale-blue apatite in small grains. Still nearer the junction, granular aggregates of tourmaline become abundant, and the mica passes to a distinctly coarser form. The

Meldon aplite contains blue apatite, but practically no tourmaline.

Admittedly, this almost pure aggregate of lithia-mica as the ultimate and extreme form of contact-alteration of the shales is surprising. But the evidence is absolute, and in some places the thin end of a large wedge-shaped inclusion will take this form, while the porcellanite type occurs where the inclusion is more massive.

It is interesting to note that the tourmalinization of the calcareous shales by the Meldon aplite is negligible, being confined to slight action on the smallest inclusions; fluorite does not occur in the shales, but in Q. III, the most massive fluorite yet found occupies cracks in an inclusion of 'dark igneous' rock; axinite is confined to near the margin of the dyke; datolite does not seem to be present in any slide as yet prepared. In other words, those minerals which might arise by fluoric and boric emanations from the dyke are practically absent in the shales, the secondary minerals of which, although some may conceivably contain fluorine or boron, or both, are yet such as, in the absence of these problematic constituents, may have been derived from the recombination of materials present in the unaltered shales. Perhaps the addition of a little soda may have been necessary, but even this is not certain. And yet the dyke itself is rich in fluorite, topaz, tourmaline, and in fluor-apatite.

The larger inclusions of shale will be more fully dealt with under the heading 'Meldon Aplite' (§ VI, p. 98).

## The Meldon Limestone.

Unfortunately, specimens of this rock are now only obtainable from the quarry-waste. It is dark blue-grey, almost black: on solution in acid the pigment forms part of the residue, and, since it disappears on ignition at a bright red heat, it is almost certainly amorphous carbon. The acid solution yields a little alumina, and apparently no magnesia. There is always some residue besides the pigment, but quartz-grains are not present.

Certain specimens show small excrescences on their weathered faces, and dilute acid emphasizes these excrescences. Such specimens if treated with hot acid leave spongy black fragments, porous from the solution of the carbonate. Uncovered sections show patches of higher polish, but even in the thinnest section the calcite masks the presence of any other mineral; treated with dilute acid, however, patches are left in which this mineral, although perforated and honeycombed, shows simultaneous extinction over areas about equal to the field of a $\frac{1}{6}$-inch objective. From such rock the portion soluble in acid contains a little magnesia, while the insoluble portion yields silica, iron-oxide, magnesia, lime, and manganese—this last substance being present throughout the calcareous series.

Radiolarian chert occurs both above and below the horizon of the limestone. It is in contact with a narrow vein of the 'dark

igneous' rock at LXXVI, S.E. 59 *a*, in the L. & S.W. Railway quarry on the north side of the vein. It is in contact with the south side of a belt of 'dark igneous' rock on South Down at LXXVI, S.E. 76, and occurs freely as inclusions in the same rock. The radiolarian beds have not been carefully traced in the field, but that from 76 would appear to follow the general strike, and it has been found a little west of LXXVI, S.E. 11, on the Redaven. All these cherts so far examined show the finely laminated character referred to by G. J. Hinde & Howard Fox, in their paper on 'Radiolarian Rocks of the Lower Culm Measures.'[1] The radiolaria are best preserved in those specimens which come from contacts with or inclusions in the 'dark igneous' rock, and the recognizable examples would appear to belong to the genus *Cenosphæra* (Pl. V, fig. 6). Casts of radiolaria also occur at LXXVI, S.E. 56, at the contact with the northernmost exposure of 'dark igneous' rock in the L. & S.W. Railway quarry.

## V. The Igneous Rocks.

The felsite with micropegmatite phenocrysts.—This in the hand-specimen is buff-coloured (pale lead-coloured when quite fresh), usually dotted with small grey specks. It is readily discriminated, by its texture and colour combined, from all the other rocks of the locality. It does not appear to correspond precisely with any of the felsites described as from Sourton Tors by C. A. McMahon (5), although his No. 16 may be this rock altered by contact with the later igneous rocks of the Tors. The best exposure is at LXXVI, S.E. 25, on the eastern bank of the West Okement, and about 200 yards north of Flushcombe foot. At 25 the rock comes into contact with the 'dark igneous' series, but south of 25 there is a considerable mass which is wholly unaltered from this cause. The ground-mass is cryptocrystalline, with local variations in texture, and it is sparsely sprinkled with irregular flakes of green mica, much of which is now wholly chloritized. Euhedral and subhedral felspar occur as phenocrysts: some is devoid of all twinning, but more is twinned in an irregular and impersistent manner in pericline lamellæ. The whole of the felspar has a refractive index lower than that of quartz.

The quartz frequently exhibits very neat rhombic sections, and rarely falls below subhedral outline; inclusions of the ground-mass are frequent, sometimes flask-shaped and communicating with the outside by the neck of the flask. Needles of rutile occur in a few of the crystals, and all show cavities, usually empty so far as fluid is concerned, occasionally in the form of negative crystals.

The phenocrysts of micropegmatite are more or less irregular; but in most of them the dominant mineral, be it quartz or felspar, has at least some external crystal faces (Pl. VI, fig. 7).

It should have been noted that the quartz shows a well-marked

[1] Q. J. G. S. vol. li (1895) p. 632.

cleavage parallel to its outline. There is a little granular sphene (?). Fragments of this rock occur as inclusions in the 'dark igneous' series. One section of such an inclusion, taken *in situ* on Sourton Tors, corresponds in all respects with the foregoing description, and in especial presents a fine example of the flask-shaped inclusions in the quartz. But a new mineral appears, in the form of diverging bundles of acicular anthophyllite, freely developed in the ground-mass, and sometimes even marginally penetrating the quartz-phenocrysts. In consequence of the presence of this new mineral, the rock becomes greenish grey, and macroscopically might be mistaken for an inclusion of shale.

## The 'Dark Igneous' Series.

It may be well to state the problem which this series presents. C. A. McMahon (5, p. 341) saw in them a series of trachytes and volcanic tuffs. The tuffs he divided into

'(1) true tuffs, but highly metamorphosed, so that the cementing matrix . . has so completely lost all trace of its original fragmentary origin; it so closely resembles the base of some quartz-porphyries and some rhyolites, and has so entirely lost all trace of the agencies by which the change was effected. (2) in two or three cases . . . really igneous flows that have in their passage through, or over, ash-beds caught up numerous fragments of ejected volcanic and sedimentary material.'

R. N. Worth (6) considered that the agglomeratic rocks of the series fell under the second of McMahon's classes.

Mr. F. P. Mennell recognizes a

'main band of tuff [which] stretches from Lake, near Bridestowe, to beyond Sticklepath, and, of the numerous well-preserved rock-fragments that it contains, most are of rhyolitic or trachytic character, with some which represent altered andesites.' (Q. J. G. S. vol. lxxii, 1916–17, p. lxxxiii.)

It is common ground that igneous agglomerates are developed somewhat extensively, presenting the constant feature that, while weathered surfaces clearly indicate their composite nature, most freshly broken surfaces are apparently of compact and uniform texture, except where inclusions of sedimentary rocks exist, and have all the appearance of dyke- or sill-rocks.

The one hope of solution would appear to lie in the field, and there, while natural exposures are many, few are of themselves very useful. Not until recent years has there been any real opportunity of tracing the relations of the igneous with the sedimentary rocks, and with each other. Now, however, owing to the development of the London & South-Western Railway quarry, and of the Meldon Valleys Company's quarries, some very useful sections have been available.

Taken in order from the railway, across the strike, towards the granite the occurrences of the 'dark igneous' rocks are as follows:—

First at LXXVI, S.E. 56. Here the sedimentaries are contorted, and it is extremely difficult to ascertain the relationship of the igneous rock to the bedding of the shales. Southward in the

quarry the dyke at LXXVI, S.E. 58 is met. This has been worked through; it shows, however, not only in the present face of the quarry, but also in a spur of rock left on the south-west. Its thickness is almost 95 feet. LXXVI, S.E. 59 is another exposure, also showing on two faces of the quarry. It is bordered, especially on the northern margin at 59, by parallel veins. Next there is a natural exposure which crops out with many large boulders at LXXVI, S.E. 75, on the hill south of the L. & S.W. Railway quarry. At 15 it sends off a narrower branch from its southern margin, making an angle of about 24° with the principal belt of rock. The broader belt continues, passing under the viaduct, and reaches the bank of the West Okement at 71. The river-bed is covered with shingle and boulders, and the western bank is overlain by quarry-waste and the railway embankment: hence it cannot be proved that a sill extending from LXXVI, S.E. 70 to 68, is continuous with the 75–71 exposure, but the continuity is almost certain. This sill varies between 12 and 20 feet in thickness. LXXVI, S.E. 84–67–66–80–82 is a dyke of rock which has been classed by McMahon as a mica-diorite. The mica is wholly secondary, and specimens can be found almost free from this mineral; the structure is doleritic, and I prefer to class it as a dolerite—it has distinct affinities with the rock at 58 in the L. & S.W. Railway quarry. LXXVI, S.E. 77–76, is the southern margin of a band of 'dark igneous' rock. Other exposures occur along South Down, as at LXXVI, S.E. 22, a little south of this, from which point a band extends eastwards to LXXVI, S.E. 25, where it broadens into and interrupts the main dyke of Meldon aplite, which, however, persists as veins and minor dykes. Here also the 'dark igneous' rock comes into contact with the felsite with micropegmatite. If surface-indications can be trusted, the 'dark igneous' rock ranges hence, eastwards, side by side with the aplite, until it dies out in the aplite-quarry on the western bank of the Redaven. Although the 'dark igneous' rock dies out in this quarry, it is obvious from surface-indications that it occurs again on the course of the aplite-dyke north-east of LXXVI, S.E. 17, since blocks of 'dark igneous' rock penetrated by veins of aplite are found. Following the Redaven upwards from the Meldon Valleys Company's quarries we reach LXXVI, S.E. 39, where there is an important exposure which can be well seen in the river-bed. The last-known 'dark igneous' rock in this direction is found as surface-blocks at LXXVI, S.E. 7, on the hill above the Redaven mine; as this lies in the direction of the course of a small dyke of Meldon aplite, seen in the bed of the stream at LXXVI, S.E. 27, it is not surprising to find the aplite as veins in the 'dark igneous' rock.

Probably there are other veins, dykes, or sills of the 'dark igneous' rock which are hidden from observation; prior to the quarrying no one would have ventured to suggest that three separate outcrops of this rock occurred on the site of the London & South-Western Railway quarry. (The rock is prominent on

Sourton Tors, but the exposures have not been worked out in detail.)

Assuming the average dip of the shales between LXXVI, S.E. 39 and the L. & S.W. Railway quarry to be 50° (and this is a close approximation), then nearly 2000 feet of strata intervene between the first and last above-recorded exposures of 'dark igneous' rock, and in this thickness there is apparently no repetition.

## The Field-Relations of the 'Dark Igneous' Series and the Shales.

From these various exposures the following information may be derived as to the relations existing between the shales and the 'dark igneous' series. In one instance the 'dark igneous' rock forms a definite sill, and might be interpreted as conformably interstratified (LXXVI, S.E. 59), were it not that it sends apophyses into the neighbouring shales, some of which apophyses, meeting radiolarian cherts, have softened them and make contact on a wavy junction. Another exposure is possibly in part a sill (LXXVI, S.E. 70–68), but this when traced eastwards between 75–71 sends off at 15 a branch, which makes with the main belt an angle of 24°; obviously either the main belt or its offshoot must break across the bedding of the shales: it is probably the offshoot 15–78, and not the main exposure 71–75, that crosses the bedding. At LXXVI, S.E. 39, we may be dealing with a sill; but the evidence is not clear. None of these sills show any passage-bed between the agglomeratic rock, of which each is in part composed, and the shales either above or below. If the agglomerates were in fact tuffs, then, if subaqueous in their origin, there should be passage-beds, at least on the undersides, since the materials of these relatively coarse agglomerates could not fall, even through water, so gently as not to disturb the deposits on which they descended. This absence of any commingling would be conceivable in a subaërial tuff, but then there must certainly be unconformability—one cannot imagine, awaiting the reception of the ashes, a rock-surface which should be bare and at the same time precisely coincident with an original bedding-plane. In the definite sills there is no such unconformability.

But, in addition to the sills, there are undoubted dykes which do not conform to the dip of the shales. At LXXVI, S.E. 56, the igneous rock appears to intersect the contorted shales unconformably. LXXVI, S.E. 58 strikes with the shales; but, while their dip is 56° north-westwards, the dyke dips 68° south-eastwards. In places it has yielded homogeneous rock, elsewhere it has been agglomeratic. It has already been noted that either 71–75 or 15–78 must cross the bedding of the shales. LXXVI, S.E. 84–67–66–10–82 breaks across the strike of the shales from 67 to 84. This rock is a dolerite, and no part of this dyke has yet been proved to be agglomeratic. The exposure north and south of LXXVI, S.E. 25 is certainly out of accord with the bedding of the adjacent shales;

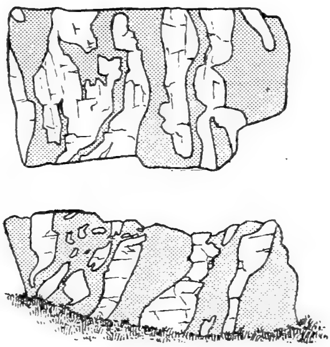
it is typical of the 'dark igneous' series and in part agglomeratic. Where this dyke dies out in the aplite-quarry on the western bank of the Redaven (Q. III) it dips counter to the shales at the same angle as the aplite, and it appears as the former occupier of the fissure of which the aplite is now the chief tenant. It is obvious that these dykes must be intrusive rocks.

So far, the broader relations of 'dark igneous' rock and shale have been described. It remains to state that every sill or dyke bakes and alters the contact-shales, and takes up inclusions of those rocks. Every sill or dyke also penetrates the shales at and near the contact. Excellent examples of this are to be found at LXXVI, S.E. 15. Here boulders occur, in which the igneous rock is seen to penetrate irregularly the shale—a good instance is sketched, the igneous rock being defined by shading (see fig. 1, *a* & *b*).

Fig. 1.—*Sketch of adjacent faces of boulder found at LXXVI, S.E. 15, showing penetration of shale (white) by igneous rock (dark).*

a.

b.



[Length of boulder = 2 feet.]

## The Petrology of the 'Dark Igneous' Rocks.

With the possible exception of the dolerite, which is rather outside the series, the 'dark igneous' rocks present a constant character, or if they vary, there are all gradations between the extremes. Their base is a cryptocrystalline ground-mass, from extremely fine to felsitic. In this base there may be either no lath microlites of felspar, or many, so many as almost to exclude the felsitic base; considerable variation in this direction may take place in one slide, extreme variation may occur in one exposure. Here it may be well to refer to a specimen from LXXVIII, N.W. 2, long. 4° 4′ $5\frac{1}{2}$″, lat. 50° 41′ $1\frac{1}{2}$″, on Sourton Tors (McMahon's locality 3). This is a grey mottled rock, with no visible porphyritic crystals. The section shows a microfelsitic base, with much granular sphene and a considerable quantity of chlorite; the mottling is largely due to magnetite, which is irregularly distributed. In places a few small felspar-laths appear, and these increase in number locally, until patches of the section are almost wholly occupied by the laths. Felsitic and trachytic texture thus reach characteristic development in the same rock, and within the area of a single section. In both the felsitic and trachytic bases there occur felspar-phenocrysts varying from

euhedral to formless. The interesting feature of this rock is that it supplies in one mass, and as variations of the same, two forms frequent among the inclusions in the 'dark igneous' rocks. Further, if the chlorite were replaced by red-brown mica, the rock would be a typical non-agglomeratic example of the 'dark igneous' series itself.

In the 'dark igneous' rocks phenocrysts of felspar may either be entirely absent, as at chilled edges (for example, LXXVI, S.E. 54, north of the viaduct, northern margin of the dyke or sill), or may be present in numbers, either euhedral or anhedral: thus LXXVI, S.E. 54 *a*, 2 feet within the margin of the dyke next to 54, shows many small felspar-phenocrysts, varying from euhedral to irregular. As a rule, felspar-crystals 2 mm. long are exceptional, but at LXXVI, S.E. 25, some slides show felspars measuring as much as 10 mm. in length. At this place many of the felspars are rather closely twinned on the albite plan, and appear to have been considerably strained, the lamellæ being thrown into gentle waves. Bent and broken felspars are to be found in slides from practically every exposure. Everywhere the felspars, when twinned, are mainly in irregular and impersistent pericline lamellæ: they are apparently orthoclase, but probably, as MacMahon believed, with intergrowths of cryptomicrocline.

Quartz-phenocrysts are never as numerous as the felspars, and may be entirely absent; usually subhedral, they are sometimes rounded. Rounded grains of quartz occur in LXXVI, S.E. 56. LXXVI, S.E. 54 *a* yields subhedral quartzes; in 'R.N.W., Meldon B,' from the collection of the late R. N. Worth (from the 71–15 exposure) some of the quartzes are subhedral, some are rounded; both are traversed by planes along which cavities have formed: the larger of these cavities show fluid and bubbles, some of the smaller appear to contain no fluid. Narrow veins of secondary quartz, sometimes with a little red-brown mica, are found in many slides.

Mica is practically always present, characteristically of a rich warm sepia, it is sometimes pale green (in contact with aplite, in the quarry west of the Redaven). Always in very minute form, its quantity varies greatly from place to place, and even in the same slide. It is this mineral that gives colour to the rock. That it is to some extent secondary is certain, it invades inclusions of shale, fills vesicles in the one vesicular inclusion seen, replaces quartz in casts of radiolaria, and takes part with quartz in filling veins. That it is wholly secondary is possible, but not certain. Pleochroic halos are frequent, but so small are the flakes of mica that one halo will frequently extend to parts of several adjacent flakes.

Tourmaline occurs in small quantity, but probably is generally distributed; it is so far rare that, unless several sections are prepared from each exposure, it may not be seen. A little bluish tourmaline occurs in 'R.N.W., Meldon B,' taken near LXXVI, S.E. 15. LXXVI, S.E. 25 also yields blue tourmaline, as does

LXXVI, S.E. 7. Brown tourmaline is developed at junctions between 'dark igneous' rocks and aplite: it is confined to the actual contact and a very narrow width within this; crystals frequently pass across the junction, lying partly in both rocks, such crystals being golden brown as regards the part within the 'dark igneous' rock, while the part within the aplite is blue (Q. III, 76).

Chlorite is very rare, but has been found in LXXVI, S.E. 76, South Down.

Anthophyllite is local, freely developed where it does occur, and certainly a secondary mineral. It occurs as groups of divergent microlites, many having the appearance of sheaves of reed very tightly tied about the middles; a typical group from LXXVI, S.E. 15, is figured (Pl. VII, fig. 17). Some groups consist of comparatively few microlites. This mineral is found in the exposures 71–75, 39, and on Sourton Tors.

## Flow-Structure in the 'Dark Igneous' Rocks.

The weathered surface of some exposures shows banding parallel to the strike (for instance, the offset 15–78 and the dyke or sill 39). This banding is sometimes so close as to amount to little more than a striation. When there are felspars of size sufficient to be readily recognized, they are seen to lie with their longer axes parallel to the bands. Microscopically these conditions are matched in some of the finer-grained specimens, in which felspar-laths are not freely developed. In these such microlites as are present tend to segregate, and to form bands in which the individuals show parallel elongation. Fig. 11 (Pl. VI) is an example from LXXVI, S.E. 15*c*. Rhyolitic structure is by no means unusual in the sections: it is frequently emphasized by the differential development of brown mica in adjacent flow-striæ, as, for instance, in 'R.N.W. Meldon, A' from near 15, and also LXXVI, S.E. 76. Flow-structure can also be detected on polished surfaces.

## Inclusions in the 'Dark Igneous' Rocks.

With the exception of 82–84 every dyke or sill is in part agglomeratic. Macroscopically there are two types. In the first, which is well developed in parts of 71–75, weathered surfaces show the inclusions very clearly, but freshly broken surfaces give practically no hint of their presence. In the second type, which prevails at 56 among other localities, the igneous inclusions are grey and clearly defined against the purple-black ground-mass, even on fresh surfaces. In the first type, the mica which colours the rock is freely developed, both in the ground-mass and in the inclusions; in the second type it is practically absent from the inclusions, but pale-green mica may occur, the original character of the fragments being the same in both. Fig. 9 (Pl. VI) reproduces a photograph of a polished surface, on a specimen from 56 *b* ($\times 2\frac{1}{2}$). The edges of the inclusions will be seen to have been rounded: the larger

fragment has been broken, and the parts separated by an invasion of the ground-mass.

The included fragments in all these rocks vary much in size, from microscopic to some inches in diameter (shale-fragments may be 6 inches or more in length). They also vary greatly in number: sometimes they are absent, in which case the rock has a subconchoïdal fracture, sometimes they overshadow the ground-mass. Variation in this respect is extremely irregular, it is as marked along the strike as across the strike. Thus 71–75 varies from fine-grained at 75, with no visible fragments except shale, to a coarse agglomerate at 74 with many igneous fragments; the offshoot 15–78 is fine-grained, but with large shale-inclusions. The northern margin at 54 is quite homogeneous, but at 55 both shale and igneous inclusions are found. None of the igneous fragments are other than can be matched from the ground-mass of the dark igneous rock itself, or from rocks found *in situ* in contact with the dark igneous rock. It is true that one vesicular inclusion has been found (R.N.W., Meldon B) in a slide from the 71–75 exposure, and as yet no instance of vesicles in the ground-mass is known. But vesicular patches in dyke-rocks are not uncommon, one such having been discovered in dolerite from 82–84. This vesicular inclusion (R.N.W., Meldon B) has a ground of felted felspar-laths, in which are set felspar-phenocrysts of the type characteristic of the 'dark igneous' series. The vesicles are all filled, the larger with quartz, in which there are usually blades of warm-sepia mica, the smaller apparently wholly with mica. Some have a border of mica and a kernel of quartz. There are others in which anthophyllite, springing from the wall of the vesicle, has deeply penetrated the quartz.

Excepting these fragments of its own substance, the only other igneous rock enclosed in the 'dark igneous' is the micropegmatite-felsite before described. At LXXVI, S.E. 25, near Forest Mine, this felsite is in contact with the 'dark igneous' rocks, and fragments of it are common as inclusions in the latter.

The included fragments of sedimentary rock are recognizably derived from the adjacent shales, with the contact-forms of which they can be matched, except for the more intense alteration which the smaller inclusions have undergone. The derivation of the fragments from the rock forming the walls of the dykes or sills is especially clear where, as at LXXVI, S.E. 77, these are radiolarian cherts. The more ordinary shales are largely altered to quartz-mosaic, and mica, either brown or greenish brown, is frequently developed, while anthophyllite also occurs. There is sometimes developed a dusty black pigment of undetermined nature. The shale-inclusions show signs of marked softening: in LXXVI, S.E. 59, a felspar of the 'dark igneous' rock has indented itself into such an inclusion. Slide LXXVI, S.E. 15, is especially notable for the manner whereby the shale-inclusions, in which anthophyllite is freely developed, have been softened, squeezed to conform to their surroundings, and drawn out to wisps at their extremities. The deformation is more marked, in that at the

points of greatest pressure the black pigment has been more freely developed (Pl. VI, fig. 10). It should have been noted that igneous inclusions frequently show invading tongues and bays of the ground-mass.

## Contacts of 'Dark Igneous' Rocks and Sedimentaries.

Very little need be written as to these. The tendency is towards the formation of quartz-mosaic and either pale or dark mica. At LXXVI, S.E. 59*a*, a vein from the 'dark igneous' rock, itself devoid of brown mica, and hence much paler than the type, meets a radiolarian chert. At the junction is an area of varying breadth, which at first appears as though it might belong to either rock, but is really the most highly-altered part of the chert. There is not much pigment in this. Radiolarian casts are frequent, and in some instances the original structure has been preserved. Beyond this the chert, for a width of 4 mm., is strongly banded in brown, the pigment being minute mica, set in a finely crypto-crystalline ground, the intervening spaces being a coarser quartz-mosaic. The bands, which are 'cobwebby,' are bent and irregular, not always even approximately parallel, but bending one towards the other and meeting so as to enclose lenticular spaces. Within this 4 mm. a little black pigment also occurs: this becomes abruptly more prominent, and largely displaces the mica in the rest of the slide. Radiolaria occur throughout, and frequently form 'eyes,' around which the dark bands bend (Pl. VI, fig. 8).

## Dolerites.

The dyke LXXVI, S.E. 82–80–66–67–84, consists for the greater part of a dark purple-brown rock; but in places the red-brown mica which stains it is practically absent, and there the rock is pale grey. It varies much in texture, being coarsest at 80, where it consists of rather stout laths of felspar (apparently oligoclase), with some broader forms and irregular areas of the same mineral. The larger felspars have been invaded by red-brown mica, of which much is present in the ground-mass also. The other minerals are augite and green hornblende after augite, apatite, sphene, and ilmenite. 84 may be taken as the other extreme in grain: the felspar-laths are very small, the red-brown mica very minute and uniformly distributed, there is a fair amount of sphene, some grains of iron-ore are present, but augite, hornblende, and apatite are absent. One specimen has been found in which the rock is amygdaloidal, the amygdaloids consisting chiefly of green hornblende, but with a little quartz also. LXXVI, S.E. 58 shows affinity with the fine-grained rock. Microscopically the original structure is much obscured, but lath-shaped felspars of fair size evidently lay with their axes in all directions, and some stouter forms are seen. There is no evidence as to what the original interstitial minerals may have been.

There are now principally two: a pale-green actinolite, mainly forming remarkably uniform areas which consist of felted divergent prisms, rarely giving a section showing the characteristic cleavage; and a mica of warm sepia tint in felted particles of minute blades. These two minerals mingle but little. There are fair-sized forms of a black iron-ore, probably ilmenite. A pretty blue tourmaline is curiously associated with pyrite, parallel needles of the tourmaline penetrating masses of pyrite, and thus giving cross-sections of tourmaline divided by a network of the other mineral.

## Conclusions as to the 'Dark Igneous' Rocks.

A marked feature of the 'dark igneous' rocks is that they are locally agglomeratic; as such they have been identified by some geologists as metamorphosed tuffs. But, on the other hand, every exposure is also in part homogeneous and compact, with clear flow-structure. The inclusions, when present, are always fragments either of igneous rock similar to the ground-mass or akin thereto, or (and) of the contact-rocks of the sills or dykes: wherever inclusions occur, some at least are fragments of the contact-rocks. The igneous inclusions show clear signs of having been subject to surface-solution by the ground-mass: the shale-inclusions have been softened, and in some cases greatly deformed, being drawn out into mere wisps. Some of the agglomeratic rocks are certainly dykes and not sills, and as such cannot be interbedded tuffs. The best and clearest example of conformable interstratification is a sill which sends apophyses into the neighbouring shales, and these apophyses alter the shales at contact. Every exposure at some place irregularly invades the contact-shales.

On the whole of the evidence adduced above, and now summarized incompletely, the 'dark igneous' rock obviously cannot be a tuff. The even and parallel planes which bound it, and the presence of apophyses, preclude the idea of an effusive lava.

There remains the possibility that matrix and igneous fragments are both derived from successive intrusions of practically the same magma, along planes of continued weakness—the later intrusions pressing farther forward, and taking up fragments of the earlier in their course. In this manner it must have been that the 'dark igneous' rock got its inclusions of micropegmatite, and in this manner the Meldon aplite took up the large inclusions of the 'dark igneous' rock. If we extend these well-ascertained facts to the period of the 'dark igneous' series itself, the interpolation seems not only justifiable but unavoidable.

The fact that the 'dark igneous' rocks are confined to a band, even if that band be 2000 feet wide, is not overlooked: it affords no valid argument against their wholly intrusive nature, since the Meldon aplite, undoubtedly an intrusive rock, is itself confined to a band of approximately the same breadth, overlapping but not conterminous.

That intrusive rocks may take up fragments of the sedimentaries through which they pass is certain: an instance long since observed is the elvan at Pentewan, near St. Austell, in Cornwall, which is loaded with slate-fragments. That they may take up inclusions of prior consolidations of their own magma can be asserted on the evidence of the Dartmoor granite itself. Thus at Redlake, in the Erme Valley, I sank a shaft in solid granite adjacent to a kaolinized area, at CXIII, S.E. 11, long. 3° 54′ 32″, lat. 50° 29′ 7″. This, on the Geological Survey map, appears to be some $2\frac{1}{4}$ miles distant from the nearest sedimentaries. But, as always where any considerable area of kaolinized granite exists, we are near the original surface of that rock, proved in this case by an adjacent inlier of sedimentary rocks on Brown Heath, not marked on the Survey map. At a depth of 120 feet the granite contained big inclusions, measuring up to 5 inches in length, of highly-metamorphosed slate, and in addition equally big inclusions of its own chilled margin, a microgranite, which itself showed inclusions of slate. Both sorts of inclusion are sharply defined and clearly bounded.

If these conditions are to be found in a plutonic rock, then an enquiry into the credentials of any apparent tuff which deviates from the normal would indeed seem necessary.

## Epidiorite (?).

An epidiorite occurs within this area; it has not been found *in situ*, but between LXXVI, S.E. 5 & 6, near Anthony Stile, surface-boulders are sufficiently frequent to indicate that this must be the approximate location of a dyke. The rock is dark green-grey. Slide 5 shows felspar, very completely saussuritized, actinolitic hornblende, and large forms of ilmenite; the felspar occurs in lath-prisms. In slide 6 the form of the felspar is preserved, but it is subdivided into smaller areas, and the mineral is remarkably clear. Obviously it has been reconstituted: it may now be an acid labradorite. The actinolite is as in 5, and the ilmenite is in more skeleton form. No augite nor apatite occurs in either slide. At Sourton Tors C. A. McMahon described certain epidiorites (5, p. 340): these, as shown in my sections, are finer-grained rocks with less hornblende.

## VI. The Meldon Aplite.

I use the term 'aplite' with some reserve, and solely because it has frequently been applied to this rock and has become familiar; a more accurate, if more cumbersome, description would be 'lepidolite-soda-granite.'

The typical Meldon aplite is not confined to one dyke; but, since its geography has never been adequately dealt with, it might be as well to refer first to the northernmost or main dyke.

De la Beche's survey shows two isolated patches—the one on the Redaven and the other on the Okement. As late as 1915

Mr. F. P. Mennell[1] writes of the aplite as a large irregular intrusion. But long before this, Frank Rutley, in 1889, had recognized the rock as occurring in an intrusive dyke or sheet, which he believed extended over a mile in length (3); and, in 1893, C. A. McMahon had spoken of it as a long straight dyke.

The extreme points at which the main dyke has been found *in situ* are: to the south-west LXXVI, S.W. 6, old ice-ponds, Sourton, and to the north-east LXXVI, S.E. 17, the boundary of the enclosed land near the Redaven. The distance between these extremes is 3344 yards, or nearly 2 miles, and the dyke certainly extends beyond 17 north-eastwards. On the map (Pl. VIII) full black circles and a full line indicate actual *in-situ* exposures; open circles and a dotted line show where the mapping has been done from surface-stone; the thinner dotted line, marked 'approximate,' covers a length where the grasslands practically obliterate all indications, and where it is known that for some distance the dyke never reached the surface.

LXXVI, S.E. 17, is part of the well-known Meldon exposure; near this occur many surface-boulders of the rock, and formerly a larger number existed.

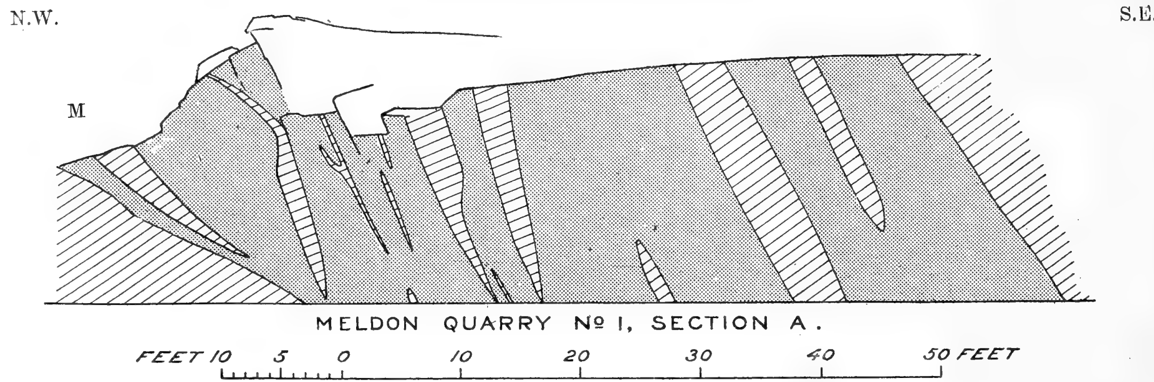
The occurrence of aplite at LXXVI, S.W. 6, was ascertained by me in 1903. The old ice-house had been sunk below ground-level, and in the excavation the dyke had apparently been struck. In May and June 1910, as a result of prospecting, the dyke, 4 feet wide, was found at LXXVI, S.W. 5, under 6 feet of rubble-head. About 125 feet away to the south-west, at LXXVI, S.W. 6, it had degenerated into three parallel veins in the shale, from $\frac{1}{2}$ to $1\frac{3}{4}$ inches thick, the two principal veins being 18 inches apart. North-east from LXXVI, S.W. 5, in a length of 37 feet, the dyke became reduced to $3\frac{1}{2}$ feet in width. A trench was then dug at LXXVI, S.W. 7, about 250 feet from 5, and in this and another pit only 67 feet from 5 no Meldon aplite was found; but in the line of the dyke the shale for a width of 6 feet was altered to a pale-grey porcellanite. Similar conditions prevailed at the hedge round the Vellake enclosures. Obviously the dyke exists below the present rock-surface, which it has not reached. Within the Vellake enclosures no prospecting has taken place, beyond a superficial examination, which has failed to detect any boulders of aplite.

On leaving the enclosures and entering South Down, we find that the dyke is traceable by surface-indications, or by trial-pits, quarries, or *in-situ* exposures, for the whole of the remainder of its ascertained length. It will be obvious from the map that the dyke does not pursue a straight course, nor are its deviations fixed by a constant underlie, coupled with the varying level of the ground.

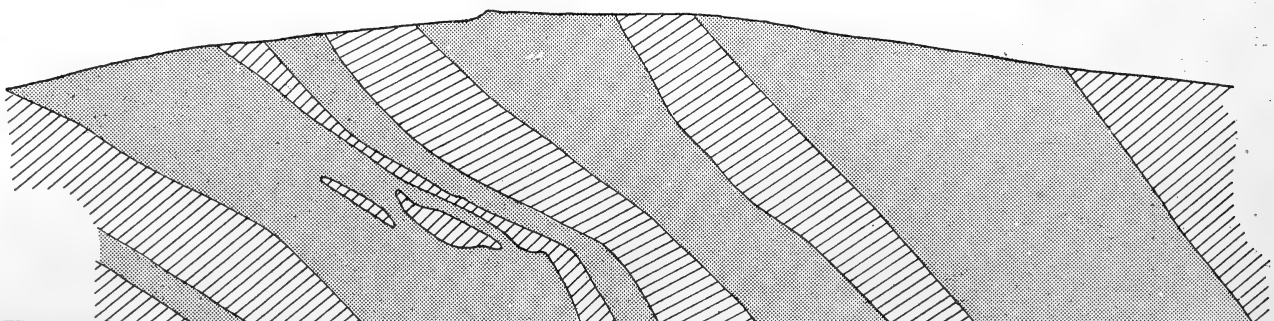
Two offshoots, other than mere veins, have been detected—the one at LXXVI, S.E. 19–64–65, the other at LXXVI, S.E. 23. Both have been quarried.

[1] Q. J. G. S. vol. lxxi (1915–17) p. 636.

Fig. 2.—*Sections in Meldon Quarry No. 1.*




MELDON QUARRY No I, SECTION A.



MELDON QUARRY No I, SECTION B.

On the Redaven the dyke reaches the surface at 830 feet above Ordnance datum. Its highest point on Sourton Tors is 1250 feet above the same datum, and there the dyke is very narrow. None of the companion aplite-dykes crop out above the 1250-foot level.

The relations of the dyke with the surrounding shales are interesting. The original bedding of the shales can easily be seen where they have been altered by the aplite. They are built up of thin layers of varying original composition: some layers are mere laminæ, some may have a thickness of 12 inches. The original composition differing, the alteration-products vary also, and their history subsequent to alteration has not been uniform. In one large inclusion in the dyke, marked 'M' on Section A hereafter mentioned, there are, in a depth of about $5\frac{1}{2}$ feet, seventeen distinct layers, omitting count of thin laminæ. These layers, as the inclusion lies in the dyke, dip north-westwards 30°, and this is not far out of accord with the general dip of the shale at this point. Many layers have decomposed to a purple-brown sandy mud (which owes its colour to iron and manganese). In some of the larger inclusions matters have proceeded even farther, and these layers have wholly disappeared, leaving water-channels in their place. No great flow of water ever proceeds from these channels.

C. A. McMahon (4) wrote of the dyke as 'infolding large slabs of the slates in its arms.' At the date of his paper there was but a small quarry on the northern bank of the Redaven that he could inspect. During the past nine years much more extensive quarrying operations have been pursued continuous with this. These have shown very many slabs of shale in the dyke (they are much less frequent south of the Redaven). Sections A & B (fig. 2, p. 100) show the quarry-face at successive stages of its development; both are cross-sections of the dyke from north-west to south-east. Section A was measured when the face was about 100 yards north-east of the Redaven, and Section B represents conditions some 30 yards farther north-eastwards. The shale inclusions are indicated by parallel-line shading, the lines following the bedding; similar shading marks each wall of the dyke. Meldon aplite is shown by a stippled ground.

It will be seen that the south-eastern wall of the dyke dips at an angle of between 53° and 58°; but on the north-west side the angle is reduced to between 21° and 24°.

In Section A this alteration is evidently due to the wedge-shape of the inclusions, all of which are widest at the top, and some of which die out before the quarry-floor is reached. At the floor-level the total width of the dyke is 62 feet, and shale-inclusions occupy $6\frac{1}{2}$ feet, the net thickness of aplite being $55\frac{1}{2}$ feet. At 11 feet above floor-level, the distance from wall to wall is 75 feet, and a width of 19 feet is occupied by shale-inclusions, leaving a net width of aplite of 56 feet, or almost exactly the same as at floor-level. Section B also shows the net width of aplite at the quarry-floor as $55\frac{1}{2}$ feet, but 20 feet above that level the net width is 69 feet: possibly one of the inclusions has been floated up to levels now denuded.

The shapes of the inclusions are curious: there is no evidence of any bending, for the bedding-planes are parallel in direction throughout each slab. Evidently the cross-joints shaping the slabs existed before the aplite was intruded.

Occasionally a vertical joint-face is met with normal to the length of the dyke, and extending completely across the whole height and width of the quarry-face, passing through aplite and shale alike. Such faces must be subsequent to the intrusion. It is notable that these latter joints are peculiarly liable to be lined with fluorspar; but, while this lines the aplite face, it is not found on the face of the shale.

Where the inclusions are smaller or less numerous the total width of the dyke is usually less.

Not only does the dyke take up large slabs of the shales, but in the quarry on the south-western bank of the Redaven it may be seen to have broken off and included in its flow a considerable mass of the 'dark igneous' rock, itself intrusive in the shales; this mass is nowhere more than 2 feet thick. In this latter quarry the dyke underlies S.E. at an angle of 73°; its width, at a point where not more than 1 foot of inclusion is to be found, is 62 feet: the quarry at the present time is some 80 feet deep in rock, with 8 feet head above this.

Where the dyke crosses the West Okement, from point LXXVI, S.E. 20 on the map, to the eastern bank of the river, its direction coincides precisely with the strike of the shales.

## The Petrology of the Meldon Aplite.

Several analyses of the Meldon aplite have been made: of these the two best-authenticated are given below:—

| | A. | B. |
|---|---|---|
| $SiO_2$ | 70·97 | 71·07 (SiO₂ + TiO₂) |
| $TiO_2$ | 0·08 | |
| $Al_2O_3$ | 17·42 | 16·85 |
| $Fe_2O_3$ | 0·22 | 0·27 |
| $MgO$ | 0·25 | 0·05 |
| $CaO$ | 1·28 | 0·87 |
| $K_2O$ | 3·11 | 3·83 |
| $Na_2O$ | 5·02 | 4·92 |
| $MnO$ | 0·28 | n. d. |
| $P_2O_5$ | 0·03 | n. d. |
| $SO_3$ | 0·04 | n. d. |
| F | 0·08 | n. d. |
| $Li_2O$ | 0·004 | n. d. |
| $B_2O_3$ | n. d. | n. d. |
| $CO_2$ | n. d. | n. d. |
| Loss when calcined over 109° C. | 0·95 | 1·87 |
| Totals | 99·73 | 99·73 |

A. Analysis for commercial purposes, made by Mr. Bernard Moore, November, 1909.

B. Analysis made under the direction of Prof. P. G. H. Boswell, for the Ministry of Munitions, 1918.

As differentiating the rock from the general mass of the Dartmoor granite, analysis reveals two features only. In the first place, the iron, determined as peroxide, is but 0·25 per cent., whereas the normal granite yields both ferric and ferrous oxide, which (if determined as the former oxide) would usually reach 1·90 to 2·00 per cent. In the second place, soda is distinctly the dominant alkali; while in the normal granite there is more potash than soda, but the excess of the former is not great.

Four reliable determinations of the alkalis in the Meldon aplite are available. The mean of the four gives total alkalies as 8·70 per cent. The lowest record is 8·13, the highest is 9·20, and the intermediates are both 8·75 per cent. The relative proportions of potash and soda are, perhaps, not quite as satisfactorily determined in two of these analyses. The most probable mean values would appear to be potash = 3·40 per cent., soda = 5·30 per cent.

The specific gravity of the rock is 2·66. At or about a temperature of 950° C. the stone softens, and at 1070° C. it flows, forming a white enamel-like substance, with sometimes a tinge of cream; at higher temperatures, not precisely determined, it melts to a pale-green glass.

Heated to well below redness the rock phosphoresces, emitting white light. Tested in 3-inch cubes the average crushing strain of the Meldon aplite is 24,000 lbs. to the square inch, or 1549 tons to the square foot, as compared with Penryn Granite (Cornwall) 1060 tons, and Hill of Fare (Aberdeen) 1360 tons, both rocks noted for their strength: this is distinctly high.

The general colour is a very pale blue-grey, almost white, but there are local variations, for the greater part very restricted in their occurrence. The most usual deviation is to a pale azure—this is found near junctions with the shale, and arises from the free development of microscopic blue apatite. A much less frequent shade is rose-pink, caused by partial alteration of the felspar. Veins stained blue by apatite, or purple by fluorspar, are also found, and occasional veins of lilac or rosy-lilac colour, which will be described later. Joint-faces may be emerald-green when lined with tourmaline, rose-pink when coloured by montmorillonite, purple from the development of fluorspar, indigo-blue when apatite is present, or of a silvery lustre when coated with mica.

The body of the dyke is very fine-grained, with no porphyritic constituents; but it is traversed by veins of coarser material, in which the normal minerals, with the exception of topaz, are repeated in larger form, some felspars measuring over an inch in length. These veins are mostly narrow, a few inches being the limit of width; occasionally they pass out from the aplite into the shales.

The minerals of the aplite are:—Felspar, quartz, mica, tourmaline, topaz, apatite, fluorspar, montmorillonite, and axinite.

The texture is micrographic (Pl. VII, fig. 12). C. A. McMahon notes (4, p. 388), that a striking feature of his slides is that the prisms of felspar are sometimes bent and in some cases broken;

and that the ground-mass consists of a mosaic of quartz and felspar, 'which some writers seem to regard as proof of dynamo-metamorphism.' He sees no reason why, in this case, these peculiarities are not sufficiently accounted for by supposing that they were produced when the granite was forced through the jaws of a fissure in the slates, or by strains in the dyke when solidifying.

The 'mosaic of quartz and felspar' is, in my slides, no other than typical granitic structure in miniature. Our normal Dartmoor granites rarely show the broken felspars, partly on account of the absence from them of those small, elongated, rectangular sections which are frequent in the Meldon aplite. Such sections are peculiarly liable to injury by pressure or movement. In the present instance the breakages probably occurred when the dyke was solidifying. It appears to have been injected in a singularly fluid condition, the evidences for which are the distance to which veins only a fraction of an inch thick have penetrated the shales; the extremely fine grain of some parts of the dyke which have been chilled by contact with the shales, and the practical absence from such parts of any but very small felspar-laths (Pl. VII, fig. 13); and, on the other hand, the occasional arrangement of minerals at the surface of some inclusions. The inclusions where small may be assumed to have been thoroughly heated, and to have exercised no real chilling action; the nearest felspars not infrequently lie with their lengths normal to the junction-plane (Pl. VII, fig. 14), very much like the minerals on the walls of some metalliferous veins. It would appear very doubtful whether, when the aplite was forced through the jaws of the fissure in the shales, there were any laths of felspar already developed.

This breakage of felspars is neither universal nor general throughout the mass: most crystals in most sections are uninjured, some sections show more breakages than others, not a few show none. That there should have been strains followed, not only from the necessary pressure-reaction of the walls of the dyke, but also from the pressure of the shale-inclusions. Notwithstanding the fluidity of the rock when it was intruded, it must have presented some viscosity, or the inclusions could not have floated. Part at least of the included rock has a specific gravity of 2·90, whereas the specific gravity of the aplite is but 2·66: hence flotation unaided by viscosity was impossible, and the weight of the inclusions must have strained their surroundings; it is in their vicinity that broken and bent felspars are most frequent.

Felspar.—Both orthoclase and plagioclase are present, the latter being dominant. In the normal rock the orthoclase is anhedral, rather rarely presenting crystal faces. An ordinary diameter for its grains might be set at 0·5 mm., but some would be much smaller, and others would reach 1 mm. and over. Small crystals of albite are not infrequently present as inclusions, with sometimes a needle of tourmaline or a blade of mica, both the latter being very minute. In the coarser veins (pegmatite of some writers) all the felspars have a tendency to fair crystal outline.

Both in the normal rock and in the coarser veins microperthite occurs, and is sometimes the dominant felspar.

The plagioclase is almost pure albite, as judged by its extinction-angles. It occurs chiefly in rather broad laths, more usually with somewhat irregular ends. The size of the larger laths may be judged from the four following examples, selected from two typical sections:—(*a*) 0·75 mm. × 0·125 mm., (*b*) 1·00 mm. × 0·35 mm., (*c*) 0·50 mm. × 0·20 mm., (*d*) 0·25 mm. × 0·25 mm. The crystals are repeatedly twinned on the albite plan, sometimes combined with the pericline. The fact that some laths are broken, some bent, and some optically irregular from strain has already been mentioned.

All the felspars are relatively fresh, only slight clouding by decomposition being present (except in rare instances); this statement must, however, be qualified in that in some of the coarser veins a considerable alteration of the felspars has taken place.

Quartz in the normal rock is wholly in irregular grains, of much the same range of dimensions as the orthoclase. In one slide, from a vein of aplite penetrating an igneous inclusion (Q. III, 76), the quartz shows a tendency to rhombic outlines.

Cavities, either empty or with fluid and bubble and at times a cubic crystal, are (on the average) distinctly less prominent in size and number than in the ordinary granite of Dartmoor. In the coarser veins the cavities are larger and more numerous than in the normal rock.

Inclusions in the quartz are: mica, tourmaline, and plagioclase. Some crystals, notably in section Q. I, 70, appear almost like micropegmatite; fairly high magnifications show many small grains and sub-prismatic forms of a mineral which is probably felspar.

Mica in the normal rock is a subordinate mineral, present chiefly as small flakes of 0·25 to 0·075 mm. and less. Larger forms are sparsely scattered: three such from two typical sections are approximately rectangular, and measure 1·00 × 0·38, 0·58 × 0·50, and 0·23 × 0·38 mm. respectively. On some joint-faces, and in the coarser veins, mica is freely developed in places, and some flakes are as much as 16 mm. long. In hand-specimens it ranges from colourless to a very pale pink-brown, in sections it is usually colourless, but sometimes faintly tinted with brown; it is sometimes zoned, the centre being tinted and the margin clear. Whereever conspicuously developed it is associated with tourmaline or apatite, or with both. All flakes large enough for testing have given a strong lithium flame, and have readily fused to a pale-grey globule in the Bunsen burner; the species is undoubtedly lepidolite.

In some sections a few small ragged inclusions may be hæmatite; small flakes of fluorspar are more frequent. In the coarse veins (Q. I, 61) the fluorspar is sometimes very markedly developed in and across the cleavage of the mica; it is difficult to say whether it is an intergrowth or a replacement, more probably the latter (Pl. VII, fig. 15).

Narrow bands occur in the aplite of the main dyke, which,

while still fine-grained, are marked out from their surroundings by a generally dispersed tint of lilac or rosy-lilac; a compact substance of similar colour is also present in some of the coarser veins. Where unmixed, as in the coarse veins, the material is readily scratched by a knife. Four sections (Q. I, 4 & 10–12) indicate that this substance consists of a felted mass of mica-scales with some larger forms of the same mineral, and with topaz and tourmaline in small grains. Three other sections (Q. I, 22, 34, 39) show a similar felted structure; but the double refraction is distinctly low—too low for mica, unless by chance the flakes have approximately parallel arrangement and are viewed normal to the base, which seems very probable. The larger forms of mica are still present in these three sections. The first four sections suggest that the colour is due to lilac-tinted lepidolite. The occurrence of lepidolite in the altered shales has already been mentioned.

In some of the minor dykes the mica is a little more deeply coloured, and pleochroic halos can be seen around small inclusions. LXXVI, S.E. 38, at the foot of Homerton Hill, and *in situ* in the dyke above, yields good examples. An inclusion of ·004 mm. diameter occupies the centre of a halo of ·067 mm. diameter, the halo being thus a shell ·032 mm. thick around the inclusion. There is a curious example in which the inclusion is a globe of ·047 mm. diameter, the total diameter of the halo is 091 mm.: the halo is here a shell of ·022 mm. thickness around the inclusion. Although inner halo and outer corona can nowhere be discriminated in the mica, this looks much as though the first instance was one of inseparable halo and corona, and the second halo without corona.

T o u r m a l i n e is to be found in all specimens of the Meldon aplite, but in varying quantity. It occurs in the body of the rock, and also coating some joint-faces: in the first case it is an original constituent; in the second it appears to belong to the final stage of consolidation of the rock, and not to subsequent action. In no case is the green tourmaline associated with any such alteration of the adjacent granite as accompanies ordinary schorl-veins.

In many specimens the presence of tourmaline would not be suspected without microscopic examination. In fact, the aplite might be divided into two varieties so far as this mineral is concerned: the one in which there is very little, the other in which it is present in such quantity as to colour the rock distinctly; but intermediate conditions are very rare. The two varieties frequently make an abrupt junction, which is never either an open joint-face or a plane of weakness. Similar junctions occur between the very fine-grained chilled rock of azure tinge, which borders the larger inclusions, and the normal rock. I have described corresponding conditions in the Cann Quarry elvan.[1]

The typical tourmaline is of a beautiful emerald-green, but in the quarry on the southern bank of the Redaven there are masses of rock in which the mineral is light olive-green, and this

[1] Trans. Devon. Assoc. vol. xxxiv (1902) p. 505.

with occasional blue tints is the colour in all the minor dykes. Portions of the emerald-green crystals are sometimes of a fine bright blue. The late R. N. Worth recorded the pink form, rubellite (6): this was an instance of close observation combined with good luck; the amount open to his inspection was but small, and in nine years' development of the quarries I have only found one block that contains rubellite. The colour is a fine clear ruby, and rarely extends over the whole of a crystal. In some instances one end of a crystal is red and the other end colourless. Some crystals are red in the central third of their length, green at each end, and colourless between the red and green. The specimen, which comes from one of the coarser veins, contains emerald-green, blue, red, and colourless tourmaline.

At the junction with the sedimentary rocks there is sometimes a slight development to black schorl, cinnamon-brown to indigo in section (Q. III, 60): this is occasionally associated with axinite (Q. III, 36), and the tourmalines are zoned in brown and indigo, the brown forming the core. At junctions with the igneous inclusion (Q. III, 76) tourmaline is frequently developed, some crystals crossing the junction; this mineral in the inclusion is golden brown, in the aplite near the junction it is blue, and where a crystal is common to both its ends vary in colour. Away from the actual contact there are slight patches of blue in the inclusion-tourmalines, and some golden-brown crystals with outer zones of blue in the aplite.

In the normal rock tourmaline occurs in irregular grains and in prismatic forms, a fair average for the larger of the latter would be 0·50 mm. by 0·25 mm. The prisms are usually somewhat ragged at the ends. The grains are pitted and perforated by inclusions, many of which are certainly quartz. Parallel growths of tourmaline and topaz occur: as, for instance, in Q. I, 71, where a topaz-crystal and a tourmaline have grown side by side with the same elongation and extinguish together.

In LXXVI, S.E. 27, a dyke crossing the Redaven above the quarries, rather long needles of tourmaline occur as inclusions in topaz, and are so oriented as to extinguish simultaneously with that mineral. On the other hand, in LXXVI, S.E. 38 (base of Homerton Hill) the pale-brown tourmalines frequently enclose topaz in parallel growth; in this slide and this only the tourmaline sometimes takes on a blue tinge at the contact with the topaz.

Tourmaline is frequently moulded upon felspar, as in Q. I, 25 (Pl. VII, fig. 16), especially upon the plagioclase-laths: the figure shows two patches of tourmaline, both belonging to the same crystal, divided by a felspar which itself is a Carlsbad twin. But the mineral very rarely occurs as inclusions in felspar. On the other hand, in LXXVI, S.E. 20 (South Down Quarry) tourmaline occurs in ophitic plates enclosing felspar-laths.

The mineral is often in close association with apatite. Zoning and local coloration are common, especially in the olive-green variety, the centre of the crystal being the darker, except in rare instances.

Pleochroic halos around inclusions are somewhat difficult to detect in the emerald-green mineral, but are well marked in the olive variety. The halo is accompanied by an outer corona, and both are in blue shades whatever the colour of the crystal. Measurements are very consistent, the radius of the halo being ·02 mm. and of the corona ·032 mm. An inclusion in the tourmaline of LXXVI, S.E. 27, Redaven, almost parallels the inclusion in the mica of LXXVI, S.E. 38; it is globular, ·041 mm. in diameter, and surrounded with a halo ·022 mm. thick—there is no corona.

It appears certain that tourmaline crystallized simultaneously with albite, with topaz, and with apatite. Only in one slide, LXXVI, S.E. 22 (South Down), are there a few small radiate aggregates of needles of this mineral.

Topaz.—First recorded at Meldon by Sir Jethro Teall (2), since spoken of by the Geological Survey as probably more frequent than in any other granite in the West of England. This statement requires some modification: if for 'granite' we substitute 'granite occurring in quantity,' then it would perhaps be near the truth; but veins in Dartmoor granite and its bordering rocks sometimes show more and better developed topaz than the Meldon aplite, whether main or minor dykes. A vein or dyke in the sedimentaries in the valley of the Lyd, near Great Nodden, may be cited; but, as to this, I have been anticipated by Mr. F. P. Mennell.[1] A more striking example would be LXXVIII, N.W. 4, long. 4° 4′ 4″, lat. 50° 27′ 4″, *in situ*, bed of the Avon above Shipley Bridge; this is a vein in the granite, and topaz is not only present in quantity but in exceptionally good outline.

In every slide of the Meldon aplite there is some topaz, and in but few is it comparatively scarce: Q. I, 29 is most marked in this respect. Often merely granular, it not seldom occurs in approximately rectangular forms, and occasionally shows good basal cleavage. In the specimens from Sourton Tors it is as well developed as anywhere, the larger forms measuring about 0·63 mm. by 0·37 mm.: these are distinctly rare.

Topaz is associated with tourmaline and with apatite in such a manner as to indicate that it was one of the earlier minerals to crystallize; there is no ground for the suggestion that its presence is due to absorption of some part of the neighbouring sedimentary rocks. The nature of the sedimentaries, whether calcareous or aluminous, exercises no influence, and further the extremely-low iron content of the aplite shows that no such absorption can have taken place. It will also be remembered that, as in one instance cited above, topaz may be freely developed in veins penetrating the granite itself. A more suggestive fact is that on Dartmoor richness in topaz is associated with poverty in mica.

Only in one slide, LXXVI, S.E. 8, south of Forest Mine, is the topaz in any way altered, and there pale mica is marginally developed—this is from one of the minor dykes.

[1] Q. J. G. S. vol. lxxi (1915–17) p. 635.

Apatite is invariably blue, reaching a deep indigo where it is freely developed on joint-faces. It is doubtful whether it is entirely absent from any section of the aplite; in some it assumes importance as a rock-forming mineral.

The azure colour of the Meldon aplite where it has been chilled is entirely due to very fine granular apatite, as mentioned above. From this dust-like form it increases near some joint-faces to dimensions of over 2 mm.; slide Q. III, 82, from a vein in the aplite, shows apatite prisms 3 mm. in length, with good hexagonal cross-sections ·6 mm. in diameter.

The larger crystals have distinct pleochroism in shades of blue, the smaller grains in section are sometimes colourless. Fluorspar occurs in cracks in the apatite-crystals. The larger apatites frequently show strings of cavities such as occur in quartz: some of these contain fluid and a bubble, but the greater number appear to have been filled with purple fluorspar. Especially in sections from near joint-faces, a close association between tourmaline and apatite is to be noted, as also many instances of adjacent areas of the two minerals extinguishing simultaneously (Q. I, 43).

Veins rich in apatite traverse some parts of the Meldon aplite, in which their distinctive colour renders them prominent.

Pleochroic halos occur around small opaque inclusions; these halos are so faint that their measurement is difficult, but a radius of about ·015 mm. seems a good approximation.

Fluorspar.—This is more essentially a mineral of the joint-faces and some of the coarser veins. In colour it is mainly purple, but occasionally green. Under the microscope it is seen that the colour is irregularly splashed throughout the crystals, some of which are zoned, either in purple or more rarely in blue—both colours may occur in the same crystal.

One joint-face in Q. I, east of the Redaven, is lined with a detachable film a little less than 1 mm. thick. Sections show this film to consist of fluorspar and quartz: the latter much clouded in parts, but sometimes in clear sharp crystals; the former colourless, except for purple and blue zones. Fluorspar occurs as inclusions in mica and in apatite, and associated with axinite. It is present in varying quantity in different parts of the main dyke, and is as prevalent at Sourton Tors as at any other locality. Occasionally a vein rich in fluorspar traverses the main dyke. In the minor dykes the mineral is extremely rare.

Montmorillonite was first reported by Mr. H. J. Lowe (7). Since his discovery the development of the quarry has yielded some very fine specimens. It is especially prevalent near the Redaven, and the best examples all come from the coarser veins. Of a beautiful rose-colour, it has a waxy lustre, and can be scratched by the thumb-nail. It forms an apparent matrix, in which are set crystals of white felspar, quartz, mica, and green tourmaline. It would appear to be an alteration-product of some

of the felspar, due to an action which has been without influence on other of the felspar-crystals.

Montmorillonite is not wholly confined to the coarser veins, for a rare example of the normal rock can be found suffused by a rose tint, and becoming almost wholly rose-coloured along certain planes; in these specimens the unaltered felspars are more than usually fresh. Yet other instances occur, in which some of the felspars of the fine-grained rock have assumed a rosy colour, but retain their hardness unimpaired.

Alteration to montmorillonite is not the only disease that has attacked the felspars of the coarser veins. At one point in the quarries, and so far at one only, some of these crystals were found converted into a rather sandy, friable, yellow substance, while still retaining traces of the original cleavages.

Axinite.—This, so far as the aplite is concerned, occurs only at the contact with the sedimentary and 'dark igneous' rocks. The crystals are pale brown or violet, and of the characteristic form. When found the mineral is freely developed, but it is of rare occurrence. There is always a little associated fluorspar, and occasionally some dark tourmaline.

## The Minor Aplite-Dykes.

Excepting the offsets at LXXVI, S.E. 19–64–65 and 23, and a few trivial veins, there is no aplite north of the main dyke. The offsets mentioned are petrologically identical with the main mass: 23, near the Redaven, was quarried into, under the belief that it was a part of the principal mass; it was found to be 7 feet wide, yielded some of the best specimens of green tourmaline, and terminated abruptly north-eastwards in a square end against the shale. At some time 19 has also been quarried.

A narrow vein of aplite occurs in the shale at LXXVI, S.E. 18, about 200 feet south-east of Quarry I. A little below the Redaven mine a dyke crosses the stream; it is 3 feet 8 inches wide, and at this point appears to be a sill, conforming to the dip and strike of the shales. This is at LXXVI, S.E. 27.

About 170 feet south of the confluence of the eastern tributary, another dyke crosses the stream, LXXVI, S.E. 29 *b*. This appears again in the bed of the tributary at LXXVI, S.E. 51, and between this and LXXVI, S.E. 52, three other courses of aplite appear in the bed of this tributary; the belt may be treated as being a single intrusion, which lies within the limits of the aluminous shales. At LXXVI, S.E. 52, the aplite passes at its margin into schorl-rock, the only instance found in any of these dykes. The felspars become much clouded as the schorl-rock is approached, and needles of blue secondary tourmaline penetrate them. The schorl-rock itself consists of tourmaline and quartz only; the quartz shows large cavities, many with fluid and a bubble, and a fair proportion containing a cubic crystal also.

That LXXVI, S.E. 27 is a belt of rock which extends north-

eastwards is made evident by aplite found as a vein in 'dark igneous' rock at LXXVI, S.E. 7.

Some one or more of these dykes or sills would appear to have a considerable south-westerly extension: a patch of boulders amounting to an outcrop exists at LXXVI, S.E. 60, and a single boulder at LXXVI, S.E. 61, both on Longstone Hill.

Following the line thus indicated, we find two dykes crossing the bed of the Flushcombe, LXXVI, S.E. 8, and LXXVI. S.E. 62: the latter is 5 feet wide or thereabouts, strikes with the shales, but dips counter to them; it is accompanied by narrow veins of similar rock parallel to it. LXXVI, S.E. 8, is about 18 inches wide and strikes with the shales, but dips counter to them.

At the foot of Homerton Hill, LXXVI, S.E. 38, are stones and boulders which have been shed by a dyke cropping out on the hill, at and about the 1000-foot contour. The mica in this dyke shows pleochroic halos of two orders of dimension.

The westernmost exposure that I shall mention is at LXXVI, S.E. 9 *e*, a shale-quarry in the Vellake Valley, hard by the stream. The rock contains orthoclase, microperthite, and albite, and is coarser in texture than the main dykes. There is a very little white mica. The quartz is zoned with pale-brown dust: cavities are numerous but small, some are empty, some have fluid and a bubble. The tourmaline is brown, with blue pleochroic halos. The topaz is quite fresh, shows good basal cleavage, and the biggest crystal is about $5\frac{1}{4}$ mm. long. The exposure is a dyke, exact width not ascertained, but not many feet; angle between underlie of dyke and dip of shales 45°. The shales, which are of the aluminous type, develop much andalusite at and near the contact.

Another aplite-dyke is seen across the Redaven at LXXVI, S.E. 30 *a*; its width is perhaps several feet. The last dyke of aplite on the Redaven is at LXXVI, S.E. 31; it is something over 100 feet wide.

There is at the Museum of Practical Geology, Jermyn Street, London, a specimen of similar rock, labelled as occurring between Row Tor and Scarey Tor; this was mentioned by Rutley (3), and is obviously referred to in the Dartmoor Memoir of the Geological Survey (8, p. 40). It is hardly hypercritical to suggest that the label is too indefinite for working purposes, the distance between the points named being fully a mile. Rutley, in 1889, made search for an exposure in this locality; I have since quartered the ground on more than one occasion, but no trace of the rock has been found.

Omitting this last, somewhat doubtful item, the veins and dykes of Meldon aplite are roughly parallel one to the other, and approximately parallel to the strike of the shales. They occur in a belt a little over 1000 yards wide at its broadest, bounded, except for some minor offsets, on the north-west by the main dyke. About half the width of the aplite-belt overlaps the area in which the 'dark igneous' series occurs, the other half lies towards the granite-mass.

## VII. Granite-Veins.

The granite-veins have not been thoroughly surveyed. They all lie between the aplite and the main mass of the granite, or else within the latter.

On the Redaven, between LXXVI, S.E. 32 and 33, is a dyke some 230 feet wide, which strikes with the shales. This rock is a fine-grained granite, without porphyritic constituents. The quartz shows a rough cleavage, which bears a constant relation to the direction of extinction. It is almost entirely in rounded forms, and the felspar has grown around it. But the mica, which is brown and highly pleochroic, has asserted its outlines as against both quartz and felspar, and there are some inclusions of mica in the quartz. Cavities in the quartz are rather rare, and are mostly empty; but fluid, bubble, and cubic crystal are to be found. Orthoclase and microperthite are the commoner felspars, and are somewhat clouded; albite is also present, and is comparatively clear. One grain of tourmaline occurs in the slide. Another slide (32 *a*) of a junction with the shale shows prisms of brown tourmaline with, in places, a very narrow outer border of blue, and with blue halos around inclusions.

There is probably another granite-dyke immediately north of the point at which the 1250-foot contour crosses the Redaven.

A narrow vein occurs at LXXVI, S.E. 46, bed of the western tributary of the Redaven. This is very fine-grained, of typical granitic structure. Much of the felspar is badly clouded and stained, but obviously both orthoclase and plagioclase are present. There is some original white mica and much secondary mica in the felspars.

A vein 1 foot wide lies about 200 feet below the Island of Rocks on the West Okement, at LXXVI, S.E. 4. The quartz somewhat resembles that in the aplite from LXXVI, S.E. 9. It is zoned with a dusty-brown pigment. Lines of cavities, mainly empty, but some with fluid and bubble, cut across the crystals, frequently parallel to a prism face, and thus coincident with the zoning, but elsewhere cutting across the zones. The quartz is also traversed by planes upon which a bladed mineral, apparently mica, has developed. The felspar is largely microperthite, invaded by mica along the cleavages; but there is a little much-clouded plagioclase. A little tourmaline occurs, with pleochroism, warm buff to cinnamon-brown, no halos seen. Grey-green mica is noted, only slightly pleochroic, but mingled with mica showing pleochroism from straw-colour to rich red-brown; this sometimes encloses tourmaline, and in one instance encloses andalusite in good crystal form. Andalusite and this mica are constantly associated, but there is no indication of the latter being derived from the former. The andalusite is at places in good crystal form, and its pink pleochroism is well marked; thin films of mica sometimes invade the cleavages. In the slide there is no andalusite in the shale.

Andalusite in vein-granite is not uncommon on this side of Dartmoor, it is developed in as large forms as anywhere in Ford

Quarry, South Tawton, where it was found by Dr. E. H. Young. But the richest in andalusite of any of the known veins was found by me in 1904 in the valley of the Lyd, *in situ* at LXXVIII, N.W. 4, long. 4° 4′ 4″, lat. 50° 39′ 54″.

Andalusite and topaz have not as yet been seen associated in the same Dartmoor granite; the granite or aplite may, however, contain topaz, while its contact-shale develops andalusite. It seems very probable that where the conditions are such that topaz can form, andalusite is thereby excluded.

True aplites, mica-free, constantly occur as a border to the Dartmoor granite, and are frequently of a bright-red colour—in fact, red shades are never absent from the border for any considerable length. Of these, one from this locality may be described, LXXVIII, N.E. 4, long. 4° 1′ 44″, lat. 50° 41′ 17, near Black Tor. A pink rock, with small nests of tourmaline. The felspars are orthoclase and a little albite, both with inclusions which give the red colour to the rock. Mica is absent. The quartz is in some grains fairly free from cavities; in others cavities are frequent, mostly small, irregular, sometimes empty, at others with fluid and bubble, and an occasional cubic crystal. The tourmaline is olive-brown with irregular tints of indigo, and halos of the latter colour. A fine-grained rock of granitic texture and without porphyritic crystals.

Another genuine aplite forms veins in the granite of the ridge between Yes Tor and High Willhays, LXXVIII, N.E. 3, long. 4° 0′ 39″, lat. 50° 41′ 20″. This is a grey rock, texture micrognanitic. Albite is in greater quantity than orthoclase, and the albite-crystals are more consistently broken than in any specimen of the Meldon aplite. The quartz contains relatively large cavities, many over ·025 mm. long, some are empty, but fluid, bubble, and cubic crystal are common. There is a fair quantity of rather dark tourmaline, zoned olive-brown within and indigo without, and showing indigo halos around inclusions.

Fine-grained granite also traverses the normal granite: thus at Black Tor, LXXVIII, N.E. 5, long. 4° 1′ 46″, lat. 50° 41′ 11½″, a grey rock as veins some 10 inches wide, following the vertical jointing of the Tor. This is a microgranite. The quartz usually presents rounded outlines, to which the felspar, which is almost wholly orthoclase, conforms. An occasional small crystal of mica occurs in the quartz: cavities are comparatively scarce, rather regular in form, and more usually empty, but fluid, bubble, and cubic crystal do occur. The mica shows pleochroism from straw-colour to brown-black. Tourmaline, blue and brown, in places irregularly disposed, elsewhere in alternating lamellæ. There are a few grains of sphene.

The general mass of the granite is of the normal Dartmoor type, with large porphyritic felspars. It differs from some of the Dartmoor granites, and agrees with others, in that nests of schorl, up to 2 or perhaps 3 inches in diameter, are rather freely developed. Detailed consideration of this rock is here purposely excluded.

## EXPLANATION OF PLATES V–VIII.

### Plate V.

Fig. 1. Chiastolite. London & South-Western Railway Quarry. LXXVI, S.E. 57. × 46. (See p. 82.)
2. Garnet. Quarry No. 1, near Redaven. Q. I, 77. Crossed nicols. × 21. (See p. 85.)
3. Idocrase, zoned. Dr. E. H. Young's slide, Y.J. 4. Crossed nicols. × 19. (See p. 85.)
4. Scapolite. Quarry No. 1, near Redaven. Q. I, 65. × 32. (See p. 85.)
5. Lepidolite-rock. Quarry No. 1, near Redaven. Crossed nicols. × 30. (See p. 86.)
6. Radiolarian, from chert-inclusion in 'dark igneous' rock. South Down. LXXVI, S.E. 77. × 80. (See p. 88.)

### Plate VI.

Fig. 7. Felsite with micropegmatite, near Forest Mine. LXXVI, S.E. 25. Crossed nicols. × 20. (See p. 88.)
8. Junction of radiolarian chert and vein from 'dark igneous' rock. London & South-Western Railway Quarry. LXXVI, S.E. 59. × 11. (See p. 96.)
9. Polished surface of agglomeratic 'dark igneous' rock, from London & South-Western Railway Quarry. LXXVI, S.E. 56. × $2\frac{1}{2}$. (See p. 94.)
10. Deformed shale-inclusion in 'dark igneous' rock from Loading Bank. LXXVI, S.E. 15. × 12. (See p. 96.)
11. Band of microlites in homogeneous 'dark igneous' rock, from Loading Bank. LXXVI, S.E. 15 *c*. Crossed nicols. × 33. (See p. 94.)

### Plate VII.

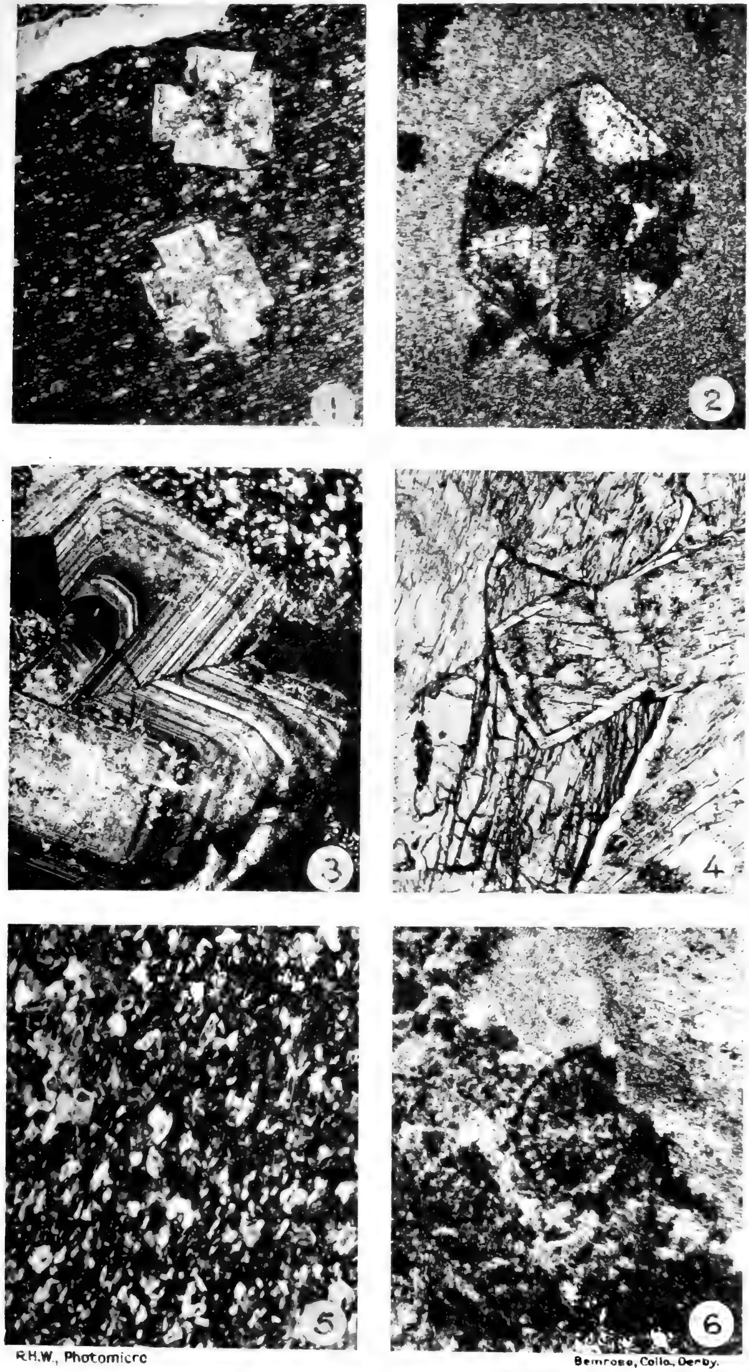
Fig. 12. Meldon aplite, standard from Quarry No. 1. Q. I, 70. Crossed nicols. × 27. (See p. 103.)
13. Meldon aplite, chilled rock at contact, azure-coloured. Quarry No. 1. Q. I, 42. Crossed nicols. × 27. (See p. 104.)
14. Felspars in Meldon aplite, normal to junction with igneous inclusion. Quarry No. 3. Q. III, 78. Crossed nicols. × 20. (See p. 104.)
15. Fluorspar in mica, from coarse vein in Meldon aplite. Quarry No. 1. Q. I, 61. × 42. (See p. 105.)
16. Tourmaline moulded on felspar, in Meldon aplite. Q. I, 25. × 23. (See p. 107.)
17. Anthophyllite in shale-inclusion in 'dark igneous' rock, from Loading Bank. LXXVI, S.E. 15. × 47. (See p. 94.)

### Plate VIII.

Geological map of the Meldon Valleys, on the scale of 6 inches to the mile, or 1 : 10,560.

## Discussion.

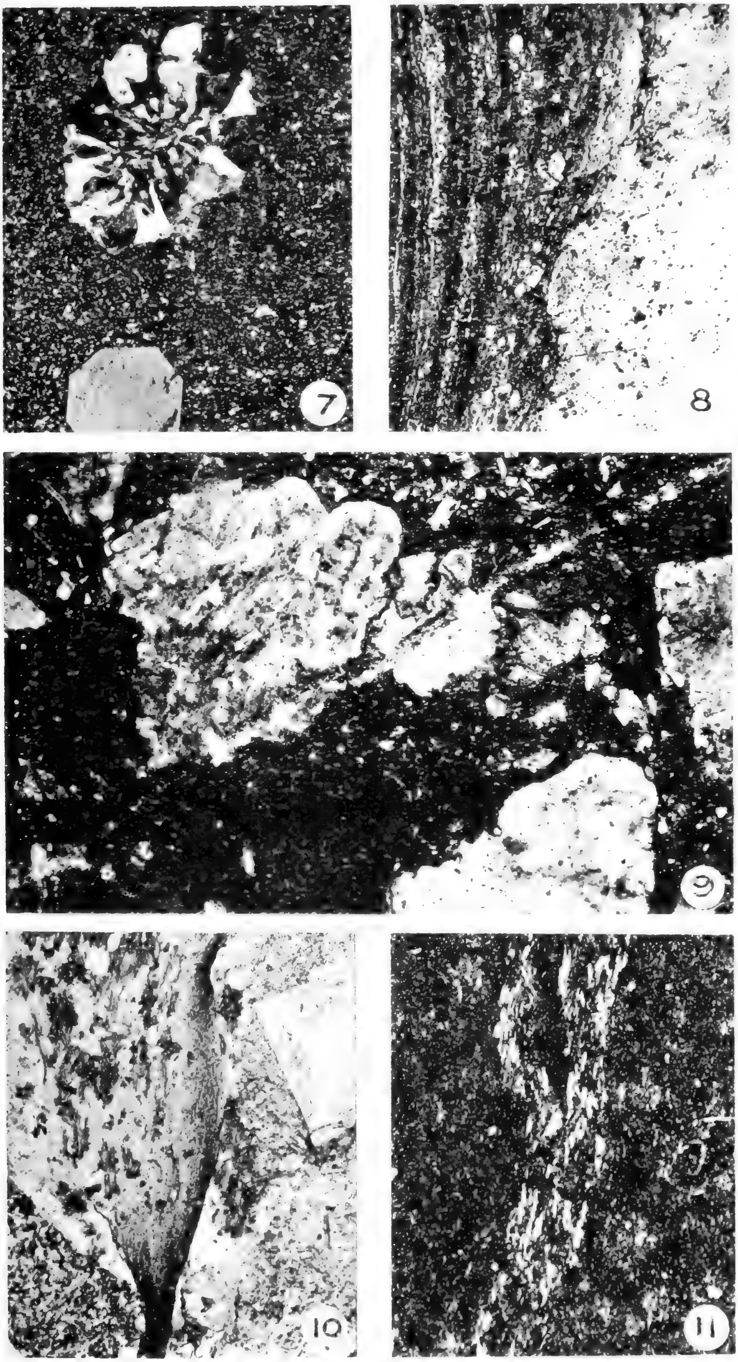
The President (Mr. G. W. Lamplugh) complimented the Author upon his clear exposition of a difficult subject. With reference to the peculiar characters of the 'dark igneous' rocks, he was reminded of the work of his former colleagues in Ireland, Mr. J. R. Kilroe & Mr. A. McHenry, who had observed intrusive




R.H.W., Photomicro

Bemrose, Collo., Derby.

MELDON VALLEY ROCKS.

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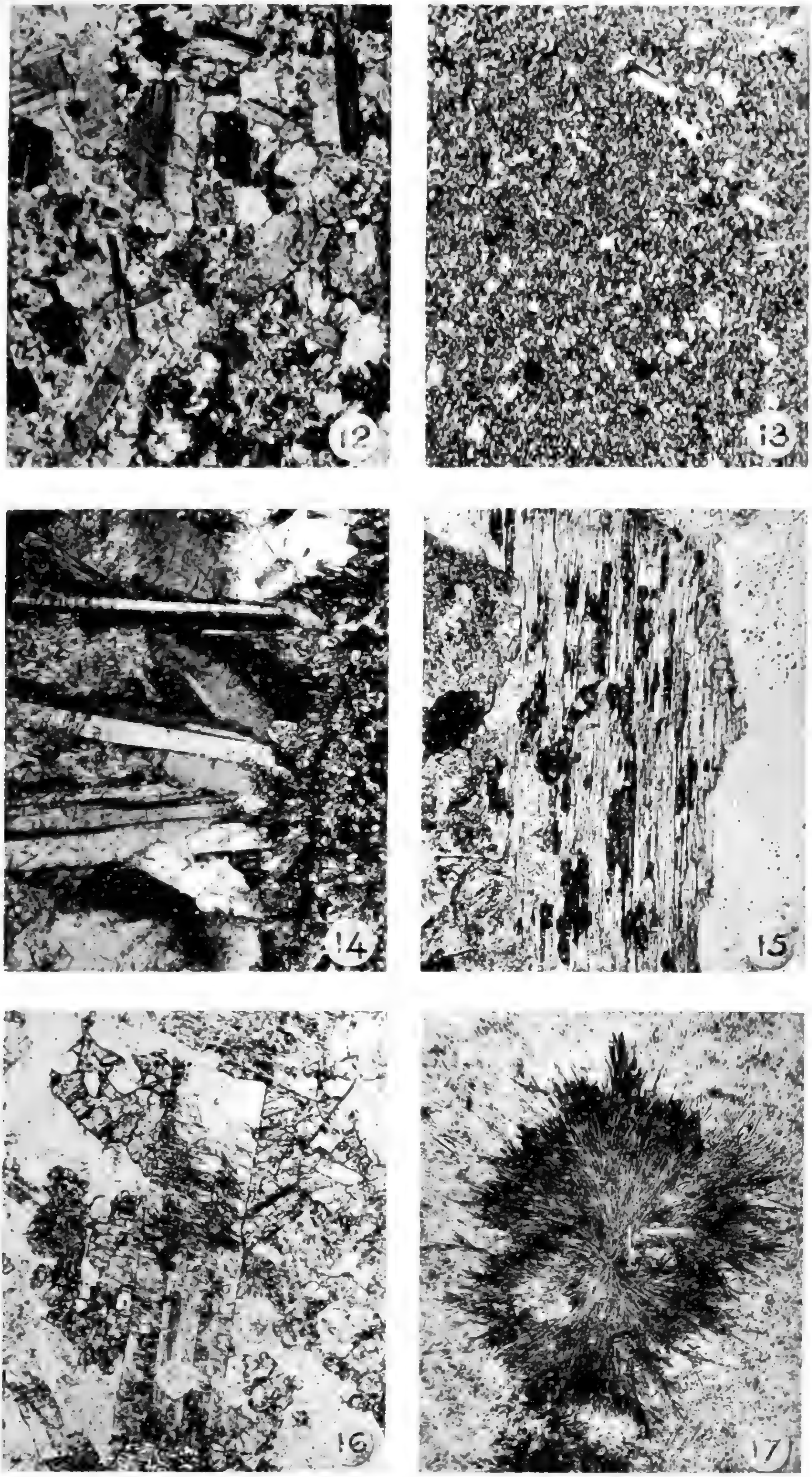
MELDON VALLEY ROCKS.

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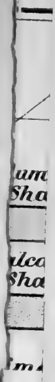
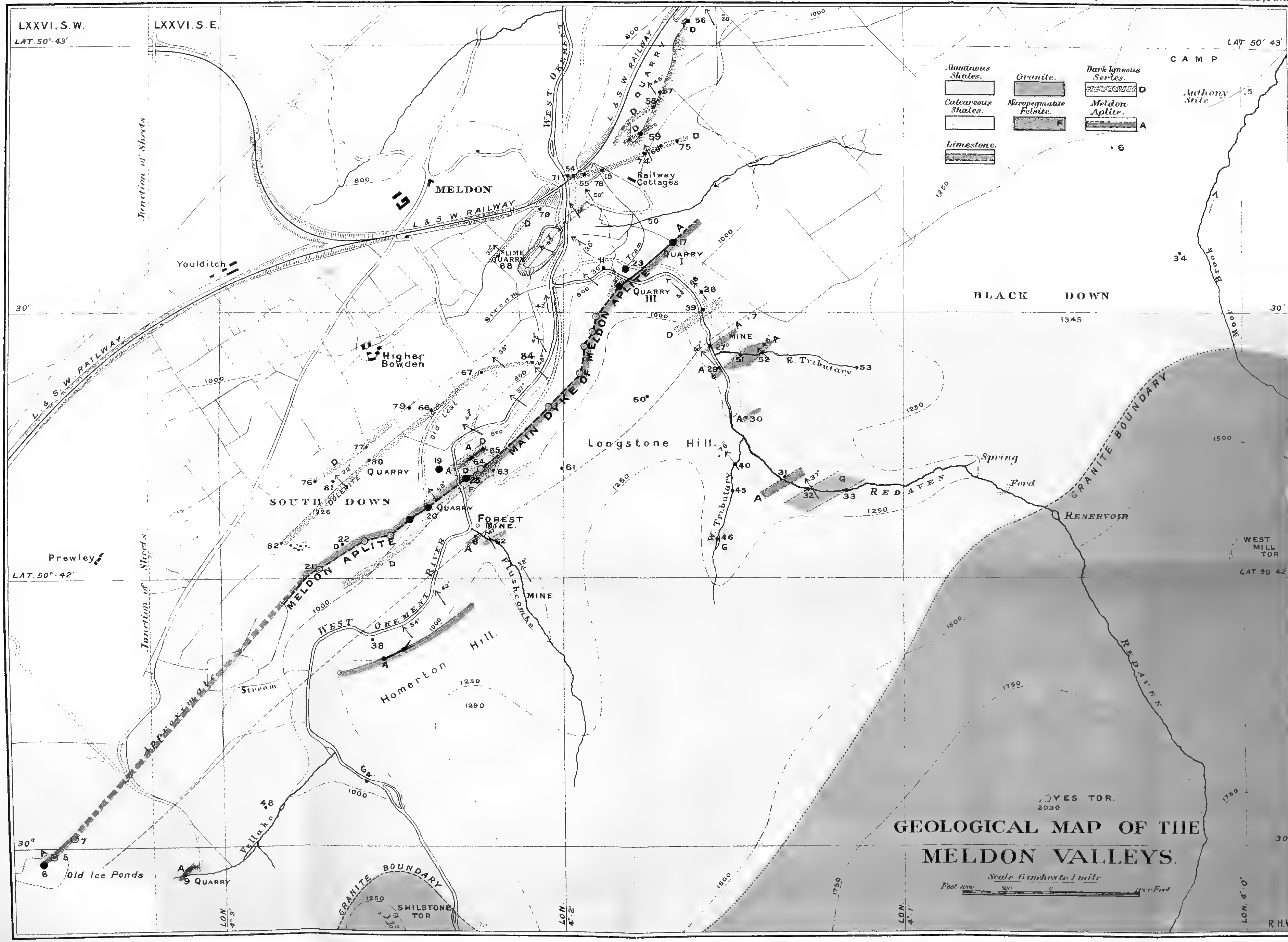
MELDON VALLEY ROCKS.






GEOLOGICAL MAP OF THE MELDON VALLEYS.

Scale 6 inches to 1 mile

H & C GRAHAM LTD LITHO LONDON S.E.

tuff-like rocks among the Lower Palæozoic strata in several parts of that island and had contributed a paper on the subject to the Society in 1901.

Dr. A. HOLMES said that the subject of the communication was of particular interest to him, as he had spent some weeks in mapping the country around Belstone, which lay immediately to the east of the district described by the Author. He had found a closely-similar upward succession of sediments dipping away from the granite-contact, though, in the absence of evidence of the kind demonstrated by the Author, he had regarded the 'dark igneous' rocks as interbedded tuffs deposited above the calcareous series. He admitted, however, that near Meldon there appeared to be unequivocal evidence of their intrusive nature; but he still wished to ask whether there was any evidence of repetition of these puzzling rocks by faulting, for in the East Okement valley he had found a repetition of the calcareous series and of the overlying tuff, the structure and metamorphism suggesting that the movement might have been due to underthrusting caused by an underground extension of the Dartmoor granite. Near Belstone the speaker remarked that he had found black chiastolite-rocks at three different horizons: one below, and two above, the calcareous series; and as all three were much below the chiastolite-rocks mentioned by the Author, he asked whether similar rocks had not been observed in the Meldon Valleys nearer the margin of the main granite.

Dr. R. L. SHERLOCK stated that he would have liked to hear more about the stratigraphy of the region. The succession of strata seemed to be similar to that in the Lydford–Brent Tor district, some 5 miles away to the south-west; but a notable difference was the absence of the pillow-lavas which, at Brent Tor, succeeded the chert. It seemed possible that the 'dark igneous' rocks might represent the pillow-lava, especially as they had sometimes an agglomeratic and sometimes a tuffaceous aspect; for both of these appearances were found in the Brent Tor lavas. However, the specimens on the table did not support this view. The method by which a pillow-lava might come to resemble an agglomerate is illustrated by the Middlesbrough slag-heaps. There the molten slag is chilled during transport in the wagons, and forms a hard skin to the still liquid interior. When tipped, the molten slag flows out, and sometimes may incorporate masses of the rind. If a pillow-lava is poured out beneath the sea, the parts in contact with the water are chilled, and the rind, being burst by the pressure behind, may be incorporated in the matrix.

Near Brent Tor the chert was perhaps 90 feet thick, and covered considerable areas, apparently forming a succession of outliers. Yet observed dips were usually high, and sometimes extreme, although the mass as a whole appeared to have but a moderate dip. This could be explained by the packing that had been caused by thrusting on an extensive scale, and it applied to all the local formations. The Author's account of 2000 feet of

strata with an average dip of 50°, bounded on both sides by the 'dark igneous' rocks, and the fact that the two districts were but a few miles apart, made the speaker doubt whether the succession was really a normal one. However, the geology of Devon is so extremely complex, that the two districts may be quite different in structure.

Dr. J. W. Evans welcomed this valuable contribution from one of the all-too-small band of local workers in Devon. He commented on the excellence of the microphotographs, and hoped that the very convenient practice of placing a scale of length on each would be followed by other authors. He was certainly under the impression, from his personal observations, that there were ash-beds interstratified with the slates near Belstone, which he had visited along with Dr. Holmes; but the Author appeared to have made out a strong case for the intrusive character of the clastic igneous rocks described by him. The speaker suggested that the relations between the fragmentary and the fluidal igneous rocks in this case might be explained by earth-movements giving rise to shatter-belts involving recently-consolidated intrusions, followed by later intrusions which penetrated into the interstices of the fragmental material. He was glad that the Author had given a description of a recent example of the extraordinarily-effective action of streams on occasions of catastrophic rainfall. Such occurrences, though they might be separated by long intervals of time, were part of the normal processes of Nature, and probably accounted for the greater portion of fluviatile erosion. The President had recently laid stress on this fact, which was as a rule not sufficiently realized.

Sir Douglas Mawson, referring to the Author's suggestion that the re-entrant angles in the outline of a cross-section of chiastolite embedded in a fine-grained base (shown in one of the microphotographs) appeared to indicate twinning, remarked that a similar feature is exhibited in the case of the wonderfully-developed crystals occurring at the famous locality of Mount Howden, in South Australia. There the individuals, which are some inches long, offer special facilities for examination in detail, but have proved to be simple and not twinned. An investigation had led him to regard, as the chief influence favouring such a development, the existence of conditions exceptionally suitable for very rapid growth of the crystals.

Dr. H. H. Thomas agreed with the previous speaker that the crystals of chiastolite were simple crystals, despite their curious cruciform habit. The crystals appeared to have developed both prismatic and pinacoidal faces up to a certain point, after which all deposition appears to have taken place upon the prism-faces, thus bringing about the suppression of the pinacoids and the formation of those re-entrant angles that give the superficial appearance of twinning.

Prof. W. W. Watts stated, with reference to the 'intrusive tuffs' mentioned by the President, that one set of these occurrences was

near Castletown Berehaven (County Cork), where sills and dykes clearly intrusive into Carboniferous rocks had proved to be of clastic character. As it was unlikely that 'sills' of this nature could be formed where the beds were horizontal, and the beds were highly inclined as the result of post-Carboniferous movement, the date of the intrusions was an interesting problem.

The AUTHOR thanked the Fellows for their kind reception of his paper. He had some knowledge of the area in which Dr. Evans and Dr. Holmes had been working, and he was inclined to agree that repetition did there occur. But, on the Redaven traverse, he had been unable to find any one bed apparently repeated, if the 'dark igneous' rocks were excluded from consideration. And these dark igneous rocks could hardly have been solitary in this respect: other highly characteristic beds would have accompanied them. One broad feature in evidence was that the arenaceous and the calcareous shales met in a well-defined boundary, and neither series trangressed that boundary. The limestone was a well-marked rock, easily identified. The earlier geological survey showed two beds of limestone, and at some time an attempt was made to open up the southern supposed bed for commercial purposes, with the result that it was proved to exist on the map only. The error probably arose from the presence of a black chert-like rock, somewhat similar to that which is the constant companion of the limestone. In his paper he had shown that there were three beds of black chert-like rock, but each had its own distinguishing features.

It appeared to him that, around Dartmoor, the chiastolite-slate had some value stratigraphically, but, perhaps, rather as marking a belt than as indicating a definite horizon.

Replying to Dr. Sherlock, he thought that the Brent-Tor igneous series had a close kinship with the spilitic series of Plymouth and neighbourhood, but was in no way related to the 'dark igneous' rocks of the Meldon Valleys, which were much more acid. The origin of pillow-lavas in submarine lava-flows could hardly be substantiated in the Plymouth district. A lava-flow over a sea-bed of sand or mud must, he thought, greatly disturb the surface of that deposit; whereas pillow-lavas were found which met the sedimentary rocks in plane surfaces, sometimes coincident with the cleavage, and with no evidence of disturbance.

Reference had been made to the recurrent liability to catastrophes such as the storm of August 14th, 1917. There was no doubt that these storms were more frequent than many thought, but they were usually limited in area and rarely revisited the same spot at any short interval. Thus, in the present instance, there was evidence that the Redaven had never been in such high flood within the historic period: yet there was a 17th-century record which pointed to a very similar occurrence in the adjacent watershed; and, within the Author's memory, two floods, nearly if not quite as severe, had been known at other points on Dartmoor. He agreed that these phenomena were sufficiently frequent to

demand inclusion among the efficient agents of erosion and denudation.

He was much interested in Sir Douglas Mawson's description of the large crystals of chiastolite, which in Australia presented the same peculiarities as the small Meldon crystals. While the prism-faces would be favourably placed for securing preferential supplies of material when once the cross form had been established, he could not yet grasp the efficiency of this preferential supply in initiating the form. In the normal prism it would appear that the prism-angle had the greatest available adjacent area of supply. But the suggestion was new to him, and he might have overlooked some essential feature.

The President and other speakers had referred to instances of intrusive dykes formerly mapped as ash. That possibility, in the absence of rather detailed field-work, was undoubted; there seemed at present to be some reaction against the tendency to identify as contemporaneous most, if not all, interstratified igneous rocks, and most, if not all, fragmentary or agglomeratic igneous rocks.

# 7. *The* GEOLOGY *of the* MARBLE DELTA (NATAL). By ALEXANDER LOGIE DU TOIT, B.A., D.Sc., F.G.S. (Read February 5th, 1919.)

[PLATE IX—MICROSCOPE-SECTIONS.]

CONTENTS.



## I. INTRODUCTION.

THE crystalline dolomitic marbles near Port Shepstone have formed the subject of no less than three communications to this Society.

That by C. L. Griesbach,[1] written nearly half a century ago, gives us the first glimpses of this interesting occurrence; the next, by David Draper[2] was fuller, but lacking in most of the important details; the third, by Dr. F. H. Hatch & Mr. R. H. Rastall[3] is a particularly valuable contribution, especially from the petrographical standpoint: the intrusive relationship of the granite is placed beyond dispute, and the operation of the action known as dedolomitization is fully demonstrated.

Consequently, it is not inappropriate that the principal conclusions arising out of the geological survey of the area (carried out in 1915–16) should be communicated through the same channel, especially as they confirm and amplify the expressions of Hatch & Rastall as to the nature of the metamorphic actions involved.

The sole point of disagreement concerns the 'boulder' of alkali-granite, which, from the evidence available, can only have formed part of an intrusive tongue in the marble, while the other reputed instances of 'inclusions' must be placed in the same category.

The object of the present paper is the description of this and certain other cases, where there has been an actual transfer of material from the intrusion across the contact to the rock invaded, a rather infrequent phenomenon, and one termed 'contact-metasomatism' by J. Barrell, and 'pneumatolytic contact-metamorphism' by V. M. Goldschmidt; the action termed 'calcitization' is also described and discussed, possibly for the first time.

[1] Q. J. G. S. vol. xxvii (1871) p. 56. [2] *Ibid.* vol. li (1895) p. 51.
[3] *Ibid.* vol. lxvi (1910) p. 507.

Fig. 1.—*Geological map of the Marble Delta.*

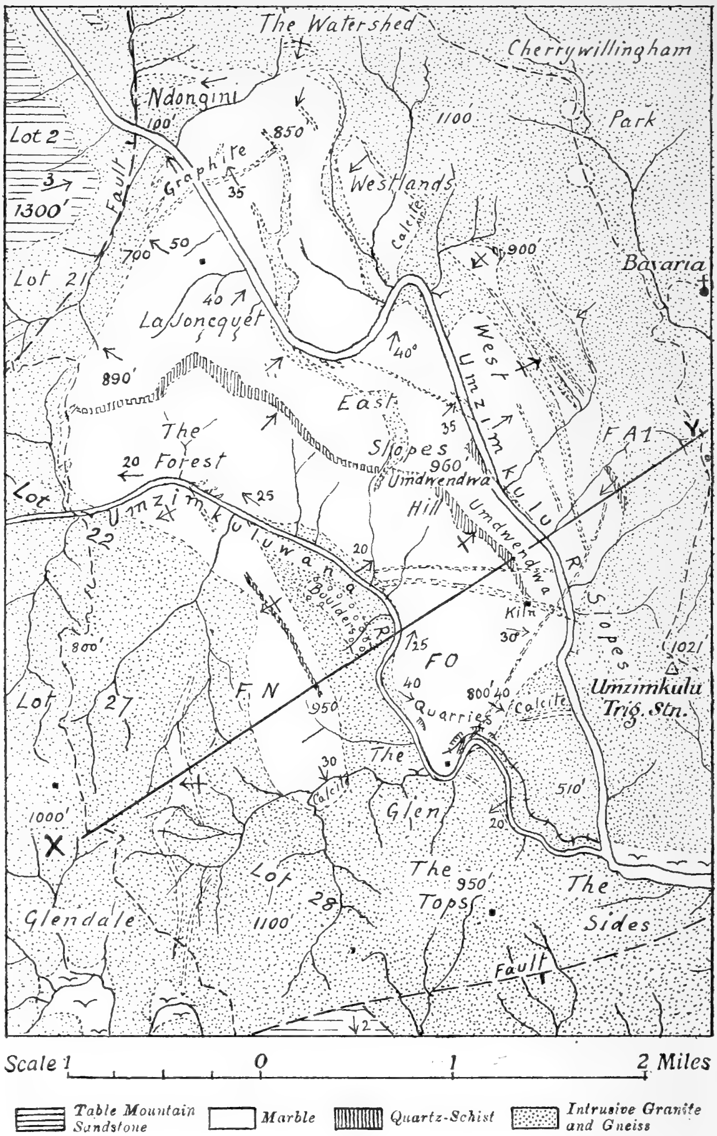
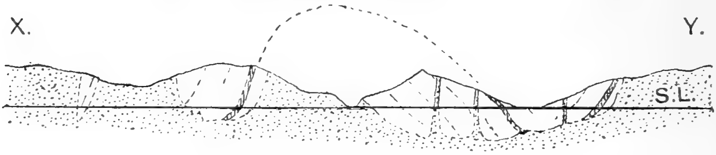



*Fig. 2 Section along line* X. Y.



A summary of the general geology has appeared recently in an account of the economic resources of the Marble Delta.[1]

While the tract is one full of problems that have an important bearing upon contact-metamorphic processes, it is unfortunate that time did not permit of more elaborate investigation in the field and in the laboratory.

Within the region embraced by the accompanying plan (fig. 1)—differing considerably from that given by W. Anderson [2]—the surface of the country forms part of a slope falling from 1500 to 1000 feet seawards, deeply trenched by the Umzimkulu and Umzimkuluwana Rivers, in the denudation of which the area has been largely stripped of its cover of horizontal Table-Mountain Sandstone, still preserved towards the west and south.

The slopes of this picturesque country are steep, and the spur between the rivers is particularly narrow; nevertheless, the frequent presence of thick bush and the abundance of fallen blocks render the tracing of boundary-lines often difficult, while there are occasional accumulations of waterworn boulders along the river-banks. There is one conspicuous terrace cut in the gneiss on the left bank of the Umzimkuluwana River, on the farm F.N., about 300 feet above stream-level, over which, as noted by Draper, there lies an abundance of large waterworn boulders, nearly all of Table-Mountain Sandstone.

## II. The Marbles.

During the course of the survey the main area of the marble was found to cover a tract almost 4 miles long by about 2 broad; it is not a solid block surrounded by granite and gneiss, as reported, but a bent and twisted mass enveloped by the igneous matter, which underlies it at no great distance and forms great inclined or nearly vertical intrusive sheets cutting across it, thus separating it into several distinct portions. On the eastern side are several parallel sills of granite parted by layers of marble. There are also several strips of marble isolated in the gneiss arranged about the borders of the principal mass.

The marbles are medium to coarse-grained rocks in which the bedding-planes can be recognized by means of lines of various contact-minerals that show up well on the weathered surfaces or through the presence of thin greyish layers. Much of the marble is pure, the percentage of silicates varying from 1 up to 5; there are types very low in carbonate, but these form only a small proportion. The formation must have a thickness of a couple of thousand feet, and is split up into an upper and a lower group by a narrow belt of quartz-schist about 50 feet thick; this includes at one point a 15-foot parting of marble. In a few places in this zone there is a little quartz-felspar rock, making it probable

[1] Mem. Geol. Surv. S. Africa, No. 11 (1918) chapt. xiii, with map.
[2] Third & Final Report Geol. Surv. Natal, 1907, pl. xxii.

that the band was originally a quartzite with a small amount of clastic felspar.

Owing to its hardness the zone forms the summit of Umdwendwe (Indwendwa) Hill; its dip is such that it just reappears along the bed of the river on the south-east, and also on the north within the great bend, and the strata can be well studied here.

The marbles resting upon this quartzose horizon appear to have carried layers of chert as well as nodules of the latter, indicated by bands and irregular bunches of tremolite up to a foot or so across, in which the crystals are nearly an inch long; conspicuous are little leaves of graphite. Most commonly there is a transition from the marble through tremolite-rock to a core of quartz; some of the features are such as would be expected to have arisen from the metamorphism of 'pre-gneiss' quartz- or chert-veins and nodules in the marble.

When the quartz-schist band is traced out, the marble mass is found to have been bent into a pitching arch, with one limb dipping north-north-eastwards or north-eastwards followed by a syncline in that direction, and the other at a high angle west-south-westwards (fig. 2, p. 120). What are apparently the lowest zones appear on F.N., the highest on Ndongini, but the original base of the group was not found, the junction with the granitic complex being everywhere an intrusive one.

The marbles are almost wholly dolomitic in composition, though bands low in magnesia are almost certainly present also. The differences between the two groups are inconspicuous; not far above the base of the upper division are some dark-weathering and finer-grained types, grey, pink, or dark red: for example, a little to the north of the south-western corner beacon of La Joncquet and in the south-western corner of The Forest. A specimen examined was dolomitic, but contained no carbonates of either iron or manganese, and the dark colour was seen under the microscope to be due to minute quartz-crystals carrying dust-like particles of hæmatite which give a maroon tint by reflected light. Another dark-red coarsely-crystalline dolomite carried, however, some carbonate of iron.

A second point of difference is that, near the top of the upper group graphite is found in layers conforming with the stratification of the marbles along a thin zone crossing the river from the northern end of La Joncquet to Ndongini. The mineral occurs either disseminated or concentrated into bands and irregular patches; the matrix is for the greater part a yellowish calcite, and, where the rock is coarsely crystalline, the graphite-flakes are larger—sometimes over a quarter of an inch across.

Graphite is, however, not at all uncommon in the marbles, in small quantity, indicating that a limited amount of carbonaceous matter was originally distributed irregularly through the formation.

The largest of the isolated marble belts is one running due north from the main road on Glendale for over a mile, and dipping at a very high angle westwards. There is a narrow parallel strip

to the east, which, where it crosses the road, is associated with a dark-banded rock composed of diopside, calcite, and olivine, the last-named mineral being altered to a mixture of serpentine and talc.

There are a few other patches of marble towards the north: namely, two on Cherrywillingham Park and one on the road-cutting nearly 2½ miles north-west of the Mehlomnyama police-camp.

Almost 25 miles in a direct line up the ravine of the Umzimkulu River is another strip of dolomitic marble[1] flanked and invaded by gneiss, and of interest because, among the types present, are some composed of chondrodite and calcite like those which will be described below.

## III. The Granite and Gneiss.

The plutonic rocks surrounding the Port Shepstone marbles are orthogneisses or gneissose granites, generally coarse-grained varieties with large porphyritic crystals of felspar, white or pink, sometimes deep red; the ferromagnesian mineral is biotite, less commonly hornblende. There are also streaks and belts of hornblendic gneisses, schists, and granulites, and it seems more than a coincidence that these rocks should so commonly be found along or close to the contacts with the marbles: for example, on Glendale, in the south-western corner of The Glen, on F.A. No. 1, Bavaria, and the northern end of Lot 21.

Such evidence as is available from this district, backed up by some from the Zululand border, leads one to infer that these basic rocks are intrusions in the dolomites that have subsequently been recrystallized by the gneissoid granite. In the narrow strip of folded leaden-grey impure marble, on the right bank of the Umzimkuluwana just below the quarries, there are layers of hornblende-granulite that behave transgressively towards the bedding, and must represent altered basic sills. These are doubtless the rocks called 'chlorite-schists' by Draper.

A very conspicuous feature of the gneiss around the marble area within a distance of from 2 up to 6 or 8 miles is the presence of red and brown garnet, and such types are frequently accompanied by pale aplitic varieties—sometimes gneissose—with an abundance of this mineral: for example, on Glendale, The Tops, and near the Umzimkulu Trigonometrical Station. Apart from this the plutonic rocks are normal, the only exception noted being a variety containing a pleochroic enstatite at Bomela Siding, 6 miles south of The Glen.

Of the offshoots into the marbles the largest is one forming a lobe running up the Umzimkuluwana almost to the northern boundary of F.N. On its western side the contact must be nearly vertical, but on the east it dips at a gentle angle below the marbles; and some good sections along the left bank show that the intrusion

[1] Ann. Rep. Geol. Surv. S. Africa for 1913, p. 88.

has made its way along the bedding-planes, and has sent little sheets in between and across the beds. Just at this point the rock is distinctly gneissose, but generally it is granitoidal, dark red, and medium-grained, with irregular bands and patches grading into pegmatite. From this lobe arise two vertical dykes of red biotite-granite, which can be traced up and across the ridge into the Umzimkulu valley, the southernmost being intersected by the adit at the limekiln on Umdwendwe, where it is somewhat gneissic in places. It is probably the dyke mentioned by Dr. F. H. Hatch. Along it the marble has been silicified, and large blocks of the siliceous product strew the slopes.

On F.A. No. 1 and the northern part of West Slopes the marble is split up by several parallel sheets of gneissic granite with a south-westerly dip, and one of these descends from the plateau into the bed of the river at the sharp bend and ascends the opposite slope on Westlands. Another sheet-like body crossing the bedding-planes and dipping westwards descends from the eastern beacon of Ndongini, crosses the Umzimkulu, and ascends East Slopes, swelling out just behind Umdwendwe Hill. This must be the granite observed by Draper, though it does not form the actual summit, as stated by him.

It is in the main a red porphyritic gneissose variety, and in places the red felspars measure as much as 4 inches across. In the bend of the river, where it cuts obliquely through the white marble cliff, are several smaller dykes. One of these is a dark-grey aplitic variety, and includes a couple of 'calcitized' marble xenoliths with cleavage-surfaces exceeding an inch in width.

So far as can be judged, all the acid intrusions—there are a few of fine-grained Karroo dolerite also—belong to and form part of the gneiss of the region. The bigger sheets are generally red, and exhibit conspicuous foliation in places; while the small dykes, of which there are a fair number, are granitic in structure and usually paler in tint, although there are some narrow red dykes as well. In the case of the very smallest injections they are generally composed almost wholly of quartz and grey or white felspar; some of them, including even 'nipped-off' portions, are distinctly foliated.

## IV. Reaction-Phenomena along Dykes.

The envelopment of the mass of dolomitic limestones by the orthogneiss has naturally caused the destruction of the original texture, and a transformation, as Hatch & Rastall have recorded, into white crystalline marble too coarse in grain to be of any use for statuary purposes, or, in the case of the impurer kinds, into varieties containing silicates.

The phenomena along granite-dykes, however, deserve some detailed consideration, because of the proof which they furnish of the actual interchange of material across the active surfaces of contact.

Special interest attaches to the occurrence regarded by Dr. Hatch as a granite-boulder embedded in the marble, the concentric rings of minerals surrounding it being held to have resulted from the reaction between the solid inclusion and the enclosing dolomite under the thermal action of the underlying intrusive gneiss and granite of the region.

From the description given by him, the occurrence perforce had to be correlated with that found in the uppermost quarry on The Glen—the only quarry that was being worked in 1909–10,—the same association of rock-types being present, although the soda-granite was undoubtedly intrusive there. It now became apparent that the so-called 'boulder'. must actually have been the tip of a granitic sill intruded almost parallel to a bedding-plane in the marble, by which the latter had been altered in the manner characteristic of igneous contacts.

A sketch of the exposure as it appeared in August 1916 is given in fig. 3 (p. 126), regarding which it must be borne in mind that the rock-face is not quite flat, and that the sill is dipping away from the observer as well as to the right. The downward continuation is hidden by the débris upon the floor of the quarry; but, on proceeding down the steep overgrown bank to the river about 130 feet below, I found three small granitic sills from 1 to 5 feet broad close together injected along bedding-planes at about the horizon of the stratum in the quarry above.

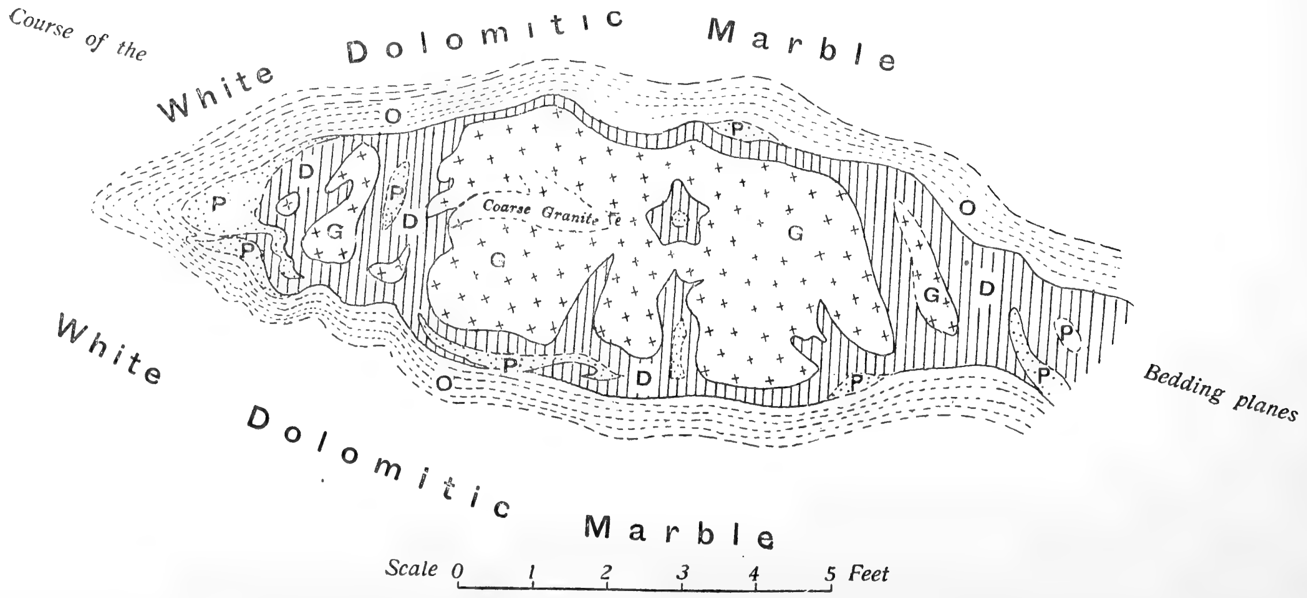
Although the largest of them differs entirely in lithological characters from the granite in the quarry, there is little doubt in my mind that the intrusions are directly connected, and that slight assimilation at the active edge of the sill and partial isolation of the magma during its crystallization account for the abnormal constitution of the latter. The margins in the quarry are fairly sharp but deeply embayed, lobes of the granite have clearly eaten their way into the dolomite, while at a distance of about 30 feet to the left, in the position where it might be anticipated, a continuation of the injection is indicated by a patch on the quarry-wall, lenticular in plan, exhibiting symmetrically arranged zones of contact-minerals just as around the exposed tongue, clearly showing that the granite is only a few inches below the surface here.

The tongue consists of a pale rock with small deep bluish-black specks of ferromagnesian mineral, rather like a riebeckite-granite in the hand-specimen: it is generally fine-grained, somewhat streaky at the top, while in places, particularly along its centre, it is coarser in texture, and composed almost wholly of white orthoclase-felspar and rather abundant quartz.

Sections 3382 & 3411,[1] cut from the granite, correspond very closely indeed with the description given by Hatch & Rastall of the 'inclusion,' except that the quartz is somewhat more rounded in outline; the cloudy orthoclase has, as they state, a delicate

[1] The numbers refer to the slides in the Geological Survey Office at Cape Town.

Fig. 3.—*Reaction-zones around a tongue of granite intrusive in the dolomitic marbles.*




G=soda-granite; D=diopside-scapolite rock; P=phlogopite-calcite rock; O=ophicalcite.
[The broken boundary-lines indicate that the limit between two types is not sharply defined.]

intergrowth of colourless albite, thus forming perthite; the pyroxene is a rich green pleochroic soda-augite in irregular areas, and often shows alteration along cracks and at the margins—especially where in contact with the quartz—to a dull bluish mass seen under a high power to consist of a fibrous intensely-pleochroic soda-amphibole; there is a good deal of sphene and a little apatite. (See Pl. IX, fig. 1.)

The coarser rock nearer the interior carries a pyroxene that is not dark blue-black but greyish-green macroscopically, colourless and non-pleochroic in thin section; it is, therefore, not a soda-augite. At its extreme margin the granite is devoid of quartz, but carries some albite and little patches of calcite.

The reaction-zones around the deeply-embayed granite are three in number, namely, a diopside-scapolite rock, a phlogopite-calcite rock, and a zone of ophicalcite, the arrangement hence differing somewhat from that in the threefold aureole described by Hatch & Rastall, which, inferentially, must have belonged to a more or less isolated protuberance from the sill, since quarried away.

The innermost zone is a pale, faintly greenish to bluish, prismatic aggregate, the individual crystals in which are set very generally with their long axes approximately normal to the granite-contact. Thin sections (3383, 3412, 3413) show that the bulk of it is formed of colourless diopside; scapolite, fresh in a few places, has mostly been altered to a brownish fibrous material, probably a zeolite: it tends towards idiomorphism. There is some calcite, an almost colourless phlogopite, and a good deal of water-clear felspar with faint repeated twinning; the felspar was the last mineral to form, and is for the greater part albite or albite-oligoclase.

The rock described by Hatch & Rastall (under the heading 3*a*), from a lump picked up in this quarry, is identical with the above and cannot be other than a fragment from this zone.

Towards the outer border of the diopside-scapolite zone phlogopite appears, at first in isolated crystals often exceeding 1 cm. in diameter, usually split up by thin films of silicates between the folia, but with faces other than the basal pinacoids present as well; calcite becomes abundant next, and is rather coarsely crystallized. The dark mica-olivine-spinel zone (3 *b*) observed by Hatch & Rastall was not noticed in the section covered by fig. 3, but from among the spoil in the quarry fragments were picked up possessing very similar characters.

Slide 3414, for example, showed abundant forsterite (partly altered to serpentine without the separation of magnetite), calcite, a very little diopside, and a fair amount of rutile, phlogopite, and colourless spinel—grey or faintly pink macroscopically. The most peculiar character of the spinel is its generally skeletal outline in thin section, due to the inclusion of the other minerals—principally calcite (Pl. IX, fig. 2): the faces of the octahedron are partly present; but the crystal is sometimes a mere shell, and it therefore differs in habit from that in the specimen described by Hatch & Rastall, in which the mineral occurs in octahedral crystals.

Outside the phlogopite-calcite zone comes the shell of ophicalcite, a distinctly banded rock composed of calcite and greenish-yellow serpentine very much like an 'Eozoon Marble'; this in turn fades away into the normal white, crystalline, dolomitic marble.

Before discussing the chemical changes involved, it would be well for comparison to consider several other marginal transformations of a more or less similar type.

Slide 3387, cut from a granitic dyke on the western side of the farm Bavaria, shows quartz, microcline, orthoclase, albite-oligoclase, and sparsely scattered pyroxene—the latter yellowish in colour with marked dispersion, and bordered by deep green pleochroic ægirite—while sphene is abundant. V. M. Goldschmidt[1] has, it might be pointed out, similarly observed an ægirite shell surrounding the pyroxene (hedenbergite) in contact-altered limestone in the Christiania region. Tiny patches of calcite are scattered about the slide, and obviously arise from undigested grains of marble.

A dyke on the western side of La Joncquet, close to the main contact, proves from the section (3377) to be a banded microcline-granite with a little augite and pale hornblende—the latter being generally intergrown with the pyroxene in parallel position,—biotite, sphene, and some graphite. This intrusion, as would be anticipated, approximates closely to the parent gneisses of the area, which, as stated, carry biotite and frequently hornblende, but not usually pyroxene.

The small granite-dykes and veins are almost invariably bordered by a zone not exceeding a few inches in thickness of pale yellowish phlogopite occurring in flakes set in planes roughly normal to the contact; and this reaction-zone is particularly valuable when we are considering certain lumps of granite isolated in the marble that might, when not irregular in outline, be readily taken for pebbles or boulders, in view of the known instances of erratics in the Chalk or Carboniferous Limestone, such as have been cited by Hatch & Rastall.

From other areas of crystalline marbles invaded by plutonic rocks the phenomenon of the disruption of dykes immediately following their injection, whereby portions of the intrusions have been nipped off and come to be isolated in the marble, is well known, while recrystallization of the country-rock destroys all effects of shearing in the mass. All the stages in such disruption can be found by search in the Marble Delta, and it is noteworthy that the broken and separated portions of granite are commonly still partly (or even wholly) surrounded by phlogopite reaction-shells. One interesting case is that of a vein about 2 cm. broad, where there is a development of pyroxene, not only on the flanks of the broken parts, but even along the irregular surfaces of

[1] Skrifter Videnskapsselsk. Kristiania, Math.-Nat. Klasse, vol. i (1911) pp. 342–44.

fracture as well, though to a less and more variable extent, proving that the disruption of this little tongue took place while the magma was yet but partly consolidated.

In another instructive instance exposed by the tramway-cutting several elongated patches of granite lie in the marble severed from the main vertically intruded vein, two of them measuring each over a foot in length, bluntly pointed at both ends, and, like the parent dyke, completely bordered by pyroxene and phlogopite shells.

A fluid, or at least a plastic, condition for these portions of the intrusion, during and immediately after its dismemberment, is indicated by the continuity of the reaction-shells, as well as by the foliated character of the igneous matter, the planes running more or less parallel to the longer axes of the lumps, and also to the length of the dyke: that is, vertically. The marble immediately around the lumps is devoid of distinct bedding-planes, but these are visible a short distance away dipping at a moderate angle from left to right.

Were it not for their relative position, ill-defined boundaries, and reaction-zones, the smaller granite-patches in the marble would certainly be interpreted as boulders.

Other fine examples of disrupted veins exhibiting similar peculiarities were found in the calcite strip on the Umzimkulu River, and the united testimony afforded by all these occurrences rules out all possibility of a xenolithic nature for such bodies.

A section (3409) from the margin of a vein 6 cm. wide in the calcite strip on F.O. shows abundant fresh scapolite—from its interference colours probably wernerite—and a greenish diopside, bordered by or intergrown with a little dark-green hornblende.

It is important to note that, whenever scapolite occurs, it is developed at the actual contact between the granite and the altered dolomite, just as has been so well recorded by J. F. Kemp & A. Hollick[1] at Warwick (N.Y.). Though the Natal occurrences are only on a very small scale, the opinion was formed that the rock belonged to the marbles; but Kemp & Hollick, dealing with bands several feet at least in breadth, have regarded it as a modification of the granite. A more suitable way out of the difficulty would perhaps be to consider the diopside-scapolite rocks as constituting a hybrid type, for they have arisen through the combination of matter contributed both by the intrusion and the dolomitic limestones invaded.

## V. The Chondrodite-Marbles.

These are interesting, partly because of the nature of the dominant mineral, and partly because of their behaviour with reference to the igneous contacts with which they are associated.

In the strip of 'calcite' on F.O. along the right bank of the Umzimkulu there are streaks of marble characterized by orange-yellow or brownish chondrodite, and these are invariably separated

[1] Ann. N.Y. Acad. Sci. vol. vii (1894) pp. 644 *et seqq.*

from the granite veins by from a few up to fully 12 inches of marble rich in diopside, scapolite, or forsterite, and grading on the other side into clear calcite, generally rather abruptly. Sometimes the mineral is scattered evenly through several inches of rock; at other times it is concentrated into narrow bands, along with either phlogopite, or spinel, or both.

At Swakopmund, in the South-West African Protectorate, are certain belts of crystalline marble evenly flanked by intrusive gneiss, showing an association of minerals identical with that at the Marble Delta. Layers rich in one or more of the minerals diopside, serpentine, phlogopite, and spinel, which (even though narrow) can be followed along the strike for long distances, mark out the original bedding-planes of the marbles. The chondrodite, on the other hand, may be scattered rather sparsely through the white marble, and when followed along the strike, the orange-coloured mineral tends to vanish but to reappear upon an adjoining bedding-plane; moreover, it never approaches nearer than a couple of yards to the gneiss-contacts. Owing to the absence of transverse dykes in that part of the belt which I studied, the behaviour of the mineral towards such intrusions could not be determined.

In the account given by Kemp & Hollick of the crystalline limestones of Warwick (N.Y.), a similar relationship holds, the chondrodite zone—with phlogopite, spinel, and sometimes fluorite, and with the calcite beyond—being separated from the granite by a diopside-scapolite zone.

Though the yellow mineral is referred to comprehensively as chondrodite, clinohumite is also included; but the specific distinction is often difficult to make, owing to the feeble development of the basal cleavage. Moreover, the two species are not unusually intergrown, in certain cases having the principal plane in common; humite is probably absent. While the yellow colour and the pleochroism will serve to distinguish the chondrodite from forsterite in thin section, there are cases in which only a limited part of a crystal is yellow, the remainder being colourless; but in such cases the whole still extinguishes simultaneously between crossed nicols.

The varieties that are without colour in thin section are, whether fresh or partly serpentinized, all but indistinguishable from forsterite, and resort must be had to the hand-specimen, in which the latter mineral possesses a greenish tint. In one instance, cited below, there was an intergrowth of the two minerals, but almost invariably and fortunately the one occurs to the exclusion of the other, a fact of prime significance.

In the instance cited, a band 5 cm. wide in the calcite is particularly rich in chondrodite and phlogopite, the former appearing in the thin section (3408) as large strongly-pleochroic grains of irregular outline, including mica and occasionally small octahedra of pale pink spinel; sometimes the mineral is in aggregates, with the prisms arranged in a more or less parallel fashion.

An interesting point is that certain of the grains, which are from 1 to 3 mm. in diameter, consist of a shell of yellow

chondrodite and a core of a colourless mineral that can only be forsterite (see Pl. IX, fig. 3). It is orthorhombic, and can hardly be colourless humite, as it has a higher refractive index and higher double refraction; a careful separation of some of the pale greyish-green mineral from the yellow shell enabled the absence of fluorine from the former to be proved chemically. The principal planes of the two minerals appear to be coincident: both alter to clear serpentine without the separation of magnetite, but that from the chondrodite may possess an extremely faint yellowish tint. The only reference to such a relationship in the olivine-humite group that I can find is one by A. Scacchi,[1] which is not available to me. There is in the section an abundance of phlogopite always bounded by the basal pinacoids, clear calcite, a little diopside, and some sphene.

A typical contact at this spot on F.O. shows a diopside-rich layer alongside the granite, followed by a few inches of calcite full of deep-green serpentine pseudomorphs after olivine, succeeded in turn by a rock very similar in texture, except that chondrodite takes the place of the olivine; this again is succeeded by practically pure calcite. The chondrodite hereabouts is in grains and aggregates up to about 1 cm. across.

Spinel is fairly abundant in this strip of marble, rather erratically distributed, and much commoner in the chondrodite-bearing varieties than in any other. It varies in colour from a deep bottle-green to a pale bluish tint, but the majority of individuals are grey and transparent, colourless in thin section.

The smallest spinels are in more or less octahedral forms, but all the larger individuals are irregular, or possess the markedly skeletal characters shown in Pl. IX, fig. 2. Some patches over 2 cm. across were found, full of inclusions of the matrix, chiefly calcite.

The mineral is very irregularly distributed, sometimes in narrow bands generally rich in chondrodite and phlogopite, sometimes associated with forsterite, but the larger individuals are frequently embedded in nearly pure calcite. That the mineral is spinel and not periclase was proved, it may be remarked, by its hardness and resistance to acids; neither periclase nor brucite, it is important to note, were seen in any of the marbles.

Chondrodite was also observed in quantity along the left bank of the Umzimkuluwana River on The Forest, near the gneiss-contact, but in close proximity to several granite-tongues; the individuals attain to a size of 1 cm. The mineral had also previously been recorded from the marble strip high up the Umzimkulu River, near the Cape border.[2]

[1] Neues Jahrb. 1876, p. 637, quoted by C. Hintze, 'Handbuch der Mineralogie' vol. ii (1897) p. 397.
[2] Ann. Rep. Geol. Surv. S. Africa for 1913, p. 88.

## VI. The Calcitization of Dolomitic Limestone.

The most curious phenomenon at the Marble Delta is the conversion under the influence of certain of the granite intrusions of the dolomitic marble into calcite through the complete removal of the magnesia present.

This action, here referred to as calcitization, though akin to the well-known phenomenon of dedolomitization, is somewhat different, for in the latter the magnesia merely becomes segregated within the scattered silicate-crystals developed throughout certain parts of the metamorphic aureole—a concentration *in situ*, it may be termed.

The initial stage in the withdrawal of the magnesia is seen in the case of small granite-veins, where the reaction-zone of magnesium-bearing silicates is separated from the dolomitic rock by a few inches of coarsely-crystalline calcite, this indicating presumably the migration of the magnesia towards the intrusion.

On a much bigger scale is the feature to which I now direct attention. For example, along the tramway immediately beyond the fourth quarry on The Glen, the marble beside the uppermost of the two nearly vertical granite-dykes has acquired a coarse texture, and consists of interlocking crystals of semi-translucent calcite from 0·6 to 1·2 cm. across, while the bedding-planes have become less distinct. Hardly represented on the lower side of the intrusion, this type of alteration extends for a distance of from about 10 to perhaps as much as 30 feet from the upper wall, the limit being ill-defined, and can be traced in contact with the dyke up the steep hillside to the old tramway about 50 feet above; it transgresses the bedding-planes of the marble, which are here dipping towards the dyke.

The body is large enough to serve as a source of agricultural limestone, and, whereas the adjacent rock averages from 15 to 20 per cent. of magnesium carbonate, the more coarsely crystalline and almost semi-translucent product contains from under 2 to about 6 per cent., the silica, iron, and alumina being low in both.

The 45-foot granite dyke near by includes a large xenolith in which the cleavage-faces of calcite are well over an inch across. A similar occurrence was recorded earlier, in § III, p. 124.

Again, on the spur descending to the bed of the Umzimkulu on Westlands there is a large body of similar rock along the main gneiss-contact, the general zone of alteration having a length of over 150 yards at least, while the depth, though uncertain owing to vegetation and talus, is probably not less than 40 feet. Six samples were taken from along this spur, the percentage of magnesium carbonate being 1·36 in three of them and 7·4, 8·7, and 10·6 in the others; the impurities ranged from 1·5 to 4 per cent., represented by minute grains of silicates and specks of graphite.

Another case is the strip flanked by gneiss on the farm F.O., on the right bank of the Umzimkulu, and dipping nearly vertically.

Along the bank it is 40 or 50 feet wide, and runs up the steep hillside to the top where it dies out; in it are a number of granite-veins, one of them rich in crystals of sphene 1 cm. long. Connected with these veins are the chondrodite- and spinel-bearing marbles mentioned earlier. The analysis of an average commercial sample showed 1·5 per cent. of magnesium carbonate and 1 per cent. of insoluble matter.

Such evidence as could be gathered in the field concerning these occurrences pointed, difficult though the explanation may be, to the calcite as being generally, not the mere contact-phase of a non-magnesian limestone-layer within the marble, but the terminal product in the metamorphism of a rather pure variety of dolomitic limestone.

## VII. Exomorphic and Endomorphic Changes.

There can be no doubt that originally the marbles were magnesian limestone, since converted through thermal (aided perhaps by static) metamorphism into crystalline dolomitic marbles, dedolomitized in places through the elimination of carbonic acid and its replacement by silicic acid. This normal type of contact-metamorphism, where no additions have been made to the country-rock, does not require further discussion; but in immediate proximity to the contacts appears the 'transfusive facies' long recognized by the French school of geologists, prominent among whom stands Prof. A. Lacroix.

In his interesting account of the recrystallized humite-bearing limestone inclusions from Monte Somma,[1] in which a shell of mica, pyroxene, or humite generally surrounds a kernel of calcite, he has definitely regarded the mineral alterations as the result of volatile emanations from the igneous rock, chiefly chlorides of sodium, magnesium, aluminium, and iron, and also fluorides, fluosilicates, and silicates of the alkalies. To this list, when the invading rock is granite, should, I think, be added silicon tetrafluoride, volatile and breaking up in the presence of water vapour into hydrofluoric and silicic acids.

Various American geologists, among whom may be named J. F. Kemp and W. Lindgren, have also given instances of what might be called 'additive' metamorphism accompanying the injection into limestone of igneous bodies: a recent review of certain North American evidence in support of, or against, the two opposing hypotheses has been given by W. L. Uglow.[2]

To such emanations must be ascribed the conversion of the marble along the contacts into a nearly pure diopside or a diopside-scapolite-felspar rock, in Natal only on a small scale, as it happens, but well known and by no means insignificant in many other parts of the world. Lacroix's description of the contact-development of

[1] 'Les Enclaves des Roches Volcaniques' Ann. Acad. Mâcon, vol. x (1893) p. 313.

[2] 'Economic Geology' vol. viii (1913) p. 19.

scapolite in Mesozoic limestones in the Pyrenees is interesting, the invading rock being lherzolite. The invariable contiguity of this reaction-zone to the igneous junction argues for only a limited range of movement for the silica, alumina, alkalies, and chlorine in this process of magmatic 'excretion.'

The presence of a shell of phlogopite postulates the transference from the magma of silicon tetrafluoride, potash, and in many cases alumina, the marbles being normally low in these two bases; an excess of the latter will obviously be used in the production of spinel.

The greater volatility of the fluorine-bearing emanations must tend to make this zone travel farther outwards, leaving between it and the granite a layer of silicates devoid of fluorides, while calcitization in the region beyond implies some inward movement of magnesia also. With a low content of alumina and potash, or in default of their outward transference, forsterite would normally form; but, in the presence of hydrofluoric acid, one of the chondrodite minerals instead, for all that would be required would be the introduction of $(MgF.OH)$ into the forsterite molecule $Mg_2SiO_4$ in certain proportions to produce one or other of that fluorine-bearing group. The antipathetic relationship of chondrodite to forsterite normally, but the occasional envelopment of the latter by the former (as shown in Pl. IX, fig. 3), strongly supports this view.

In the presence of alumina, but absence of potash, spinel would form, from which it may be inferred that, other things being equal, mainly the presence or absence of potash determines whether phlogopite should crystallize, or else a mixture of chondrodite and spinel. The possible existence of authigenic felspars in the sediment could, moreover, be invoked to explain the occurrence of mica along the planes of original stratification in the mass far away from contacts, the fluorine-bearing vapours preferentially following the bedding-planes; some of the flakes might even be regenerated clastic micas.

The endomorphic changes are much less marked, and result primarily from the absorption on a very limited scale of the dolomitic limestone by the invading magma.

Magnesia, having a greater affinity than lime for silica and alumina, is more easily digested; hence pyroxene and calcite separate from the dyke, whereas, owing to desilication, the magma becomes richer in alumina, potash, and soda, the first two seemingly tending to leave the dyke, while the last determines the development of perthite and soda-pyroxene. In brief, this is Dr. R. A. Daly's hypothesis of the derivation of the alkaline igneous rocks from carbonate syntectics.[1] In the small-scale phenomena observed in the Marble Delta this alkaline facies is strictly confined to the active margin, and does not obtain in the more central part of the intrusion, where the abnormally-

[1] Proc. Nat. Acad. Sci. Washington, vol. iii (1917) p. 659.

formed pyroxene (as shown by the peripheral development of hornblende) seems to be in process of resorption.

The account recently given by me [1] of an instance of the desilication of originally acid dykes cutting serpentine, whereby silica, potash, boron, and fluorine have passed out of the latter, leaving the magma with an excess of alumina that has separated as corundum, has a bearing upon the action under discussion.

In addition, a concentration of titanium-oxide and sometimes of sulphides is brought about, and sphene, rutile, and pyrrhotite appear, mostly in the dyke-margin, but also just within the country-rock.

Scales of graphite are to be found in some of the granite-injections: for example in a thin sill traversing the fourth quarry on The Glen, where the mineral was fairly abundant in the marginal portion, while in a second vein the graphite was abundant only at the very apex of the intrusion and yet hardly represented in the marble adjoining thereto; mention has already been made of this mineral in a dyke on La Joncquet.

The occurrence of graphite in nepheline-syenite cutting graphite-bearing limestones on the Botogolski Golez in Siberia [2] may be cited as a parallel, while the mineral has also been noticed in pegmatite near Ampe in Ceylon by F. Grünling and at Ticonderoga (New York County) by J. F. Kemp. It was discovered also in a peculiar calcite-bearing diopside-hornblende-granulite on Ndongini and La Joncquet—possibly a recrystallized basic sill—close to the horizon upon which the marbles carry graphite, as mentioned earlier.

The origin of the graphite in these Natal occurrences may be ascribed either to small amounts of hydrocarbons set free during the metamorphism of the marbles, or to the absorption of such (carbonaceous) country-rock, rather than to the reduction of carbon dioxide by hydrogen or hydrofluoric acid gases.

Coming finally to the problem of calcitization, we note an analogous occurrence in The Dolomite, near Potgietersrust in the Transvaal, at the contact with intrusive pyroxenite; but, in this case, Dr. R. B. Young [3] has shown that after dedolomitization the serpentine pseudomorphs were removed, and the cavities so formed filled in with secondary calcite from above, presumably by the action of surface-waters.

At the Marble Delta the following deductions can be drawn. First, the rock thus altered was a nearly pure magnesian limestone to start with; secondly, calcitization was only effected along certain of the contacts; thirdly, mere temperature could not have been an important factor, since, as we have seen, the alteration in one case is asymmetrical with regard to the dyke; fourthly, dolerite-dykes not improbably have no such effect, for one at

[1] Trans. Geol. Soc. S. Africa, vol. xxi (1918) p. 53.

[2] L. Jaczewski, Neues Jahrb. 1901, p. 74; see also O. Stutzer, Zeitschrift f. Prakt. Geol. 1910, p. 10.

[3] Trans. Geol. Soc. S. Africa, vol. xix (1916) p. 57.

the last-mentioned locality has certainly not changed the adjacent marble.

The simplest hypothesis is that waters charged with carbonic acid gas ascending along the contacts have removed the magnesium carbonate; for, although this substance is very much less soluble normally than carbonate of lime, under a pressure of about 5 atmospheres the former is dissolved almost exclusively from dolomitic limestone, according to a statement of Prof. E. W. Skeats.[1] Such waters could have been of magmatic origin, and would then have derived their free carbonic acid through the silication of the calcareous rocks in close proximity. In this connexion there ought to be recollected the intense silication of the marble along the dyke crossing the watershed on Umdwendwe, and also close to the main contact within the western corner of The Glen. The ultimate fate of the magnesia is a matter for speculation, but some of it may not improbably have passed into the invading magma.

## VIII. Summary.

(1) In addition to the normal type of metamorphism produced by the gneiss and the granitic offshoots therefrom there is also along contacts a phase almost identical with that affecting xenoliths of limestone in volcanic rocks, this similarity having indeed been pointed out by A. Lacroix, C. Dœlter,[2] V. M. Goldschmidt, and others.

(2) Through the action of magmatic emanations, zones possessing more or less regularity have been produced in the adjacent dolomitic marbles, of which the innermost is commonly rich in diopside and often in scapolite, with forsterite, phlogopite, chondrodite, and spinel farther away; dedolomitization is usually perfect.

(3) In the contact-zone forsterite and chondrodite are antipathetic minerals, and the latter is always the farther removed from the intrusion.

(4) In certain cases the marble beyond the silicate zone has been deprived of the bulk of its magnesia, and has been changed into a mass of coarsely-crystalline calcite.

(5) This phenomenon, termed calcitization, has probably been due to the action of carbonated waters during the cooling of the plutonic complex.

(6) The absorption of marble by the magma has led to desilication of the latter, and has caused the development of pyroxene in the intrusion; concentration in alkalies may have been brought about at the active surface, with the consequent crystallization there of a rock possessing alkaline affinities.

(7) With regard to the assimilation of marble by the gneiss upon a large scale there is no evidence from this area.

[1] Q. J. G. S. vol. lxi (1905) p. 135.
[2] 'Petrogenesis' 1906, p. 157.

[April 17th, 1920.]

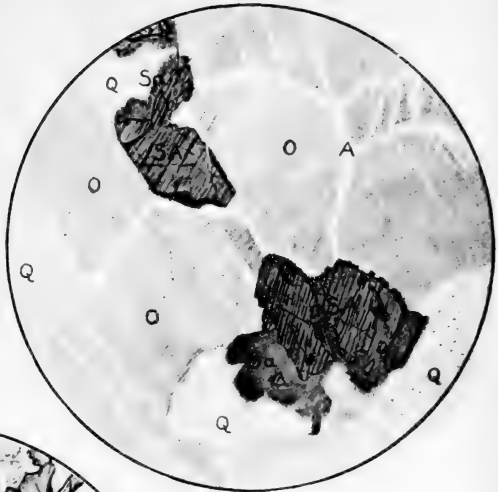



Fig. 1.
× 22


Fig. 2. × 48

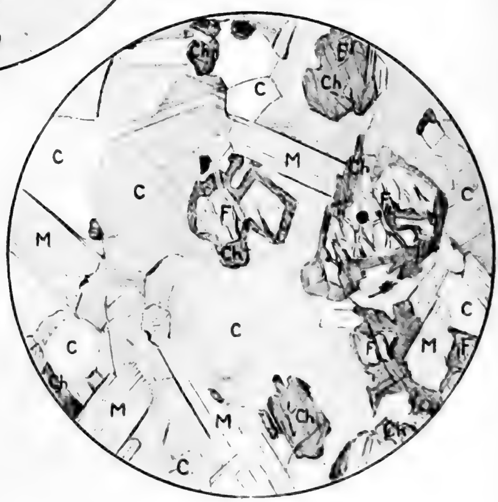



Fig. 3.
× 22

L. d T., del.

Bemrose, Collo, Derby.

ROCKS FROM THE MARBLE DELTA (NATAL).

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PAPERS READ.



[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

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The Secretaries of the Society are desirous of completing a record of the services rendered by the Fellows in connexion with the War. Details of service, with a statement of rank, regiment, military honours, and any other information, will be gladly received from Fellows, either with reference to themselves or to those known to them.

**Vol. LXXV.** **No. 299.**
Part 3.

THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY.



EDITED BY

THE PERMANENT SECRETARY.

**[With Two Plates, illustrating Papers by Dr. E. H. Pascoe and Prof. J. E. Marr.]**

June 17th, 1920.

LONDON:

LONGMANS, GREEN, AND CO.

PARIS:—CHARLES KLINCKSIECK, 11 RUE DE LILLE.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

*Price Seven Shillings and Sixpence.*

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### ORDINARY MEETING OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

SESSION 1919–1920.

1920.

Wednesday, June .......................... 23*

[*Business will commence at 5.30 p.m. precisely.*]

The asterisk denotes the date as one on which the Council will meet.

EXPLANATION OF PLATE IX.

Fig. 1. Soda-granite. Q, quartz; O, orthoclase and A, albite, forming perthite; SA, soda-augite; Sa, soda-amphibole. Magnification, 22 diameters. (See p. 127.)

2. Forsterite-spinel-marble. C, calcite; F, forsterite, partly serpentinized; S, spinel; Sp, sphene. Magnification, 48 diameters. (See p. 131.)

3. Chondrodite-marble. C, calcite; M, phlogopite-mica; F, forsterite; Ch, chondrodite. Magnification, 22 diameters. (See p. 131.)

[All under natural light.]

## Discussion.

Dr. J. W. Evans remarked on the interest of the facts disclosed by the paper. The disruption of the intrusion without any corresponding evidence of dislocation in the surrounding crystalline limestone was to be explained by the facility with which calcite, by means of its gliding planes, accommodated itself to the forces impressed upon it, so that a saccharoidal limestone might almost be said to be capable of a kind of slow, highly-viscid flow. The speaker suggested that, in this case, the crystalline limestone might be found, on more detailed examination, to show considerable variation in its magnesia-content, even where it had not suffered any change from the intrusive magma. Mr. Crook had shown that rocks composed of calcite, dolomite, and magnesia respectively, or intermediate types, might be indistinguishable in hand-specimens, except by means of their specific gravity. The evidence afforded by the chemical changes in the crystalline limestones of the volatile constituents, which must have been present in the magma when it was intruded, was of the greatest importance.

Dr. F. H. Hatch, who was unable to be present at the reading of the paper, wrote to congratulate the Author on a valuable contribution to an interesting subject. The view that the granite-fragments were older than the dolomite which contained them, postulated subsequent heating to explain the chemical interaction of which evidence was furnished by the 'reaction-rims' [1]; and this had always been a difficulty. If the Author had been able to prove that these apparent 'boulders' were in reality parts of intrusive tongues, he could offer a much simpler explanation of the facts, and one which the writer (Dr. Hatch) would be prepared to accept.

[1] See Q. J. G. S. vol. lxvi (1910) fig. 3, p. 512.

## 8. *The* EARLY HISTORY *of the* INDUS, BRAHMAPUTRA, *and* GANGES.

By EDWIN HALL PASCOE, M.A., D.Sc., F.G.S., Superintendent, Geological Survey of India. (Read March 12th, 1919.)

[PLATE X—MAP.]

THE ideas expressed in this paper are the outcome of a study of the Punjab oil-belt. The principal hypothesis proposed has been advanced simultaneously by Dr. H. G. E. Pilgrim, F.G.S., in a paper still in manuscript, to explain the formation of the Siwalik boulder-conglomerates. That paper will, I hope, soon be published,[1] but I have taken the liberty of following up an interesting point to which Dr. Pilgrim has drawn attention: namely, the frequent **V**-shaped course of the north-bank tributaries of the Ganges where they leave the belt of Siwalik deposits.

Briefly, the hypotheses that I desire to bring forward may be summarized as follows :—

(i) That in Eocene times a gulf extended from Sind northwards as far as Afghanistan, and thence curved eastwards and south-eastwards through Kohat and the Punjab to the neighbourhood of Naini Tal.

(ii) That this gulf gave place to a great river, the head-waters of which consisted of the portion of the Brahmaputra flowing through Assam. This river flowed westwards and north-westwards along the foot of the Himalaya as far as the North-West Punjab, where it turned southwards along a line not very different from that of the modern Indus, and emptied itself into the Arabian Sea. In other words, the Assam Brahmaputra was once the head-waters of the Indus.

(iii) That two separate rivers or two branches of the same river, debouching into the Bay of Bengal, cut back and beheaded this old Indus, the eastern capturing the Assam portion to form the Brahmaputra, and the western capturing gradually piece by piece the portion that intervenes between Assam and the present Jamna.

(iv) That in the meantime this old river was being still further reduced by the piecemeal capture of the portion lying between the Jamna and the Jhilam by its own tributaries, the Jhilam, the Chinab, the Ravi, the Beas, the Sutlej, and the Ghaggar.

(v) That the Attock part of the present Indus was a tributary of this old river, which at a comparatively early period cut its way back into Kashmir, where it captured the upper waters of a large river that flowed north-westwards, and either found its way into the Oxus, or curved south-westwards into Eastern Afghanistan.

The second hypothesis seems to me to be adumbrated in the second edition of the 'Manual of the Geology of India' 1893 (p. 444) by Mr. R. D. Oldham, who concludes that there are good rounds for supposing that

'the great bulk of the Himalayan drainage once found its way to the sea by a single delta, instead of two, and this must have been either at the head of the Arabian Sea, or of the Bay of Bengal.'

He then goes on to say that

'the indications of the sea having extended up the Indus valley within the recent period, and the absence of any similar indications in the delta of the

[1] This paper has since been published in Journ. Asiat. Soc. Bengal, n. s. vol. xv (1919) pp. 86–99.

Ganges, make it probable that the former was the original outlet of the drainage, and that the formation of the gap between the Rajmahal and the Garo Hills, and of the Gangetic delta, is geologically of recent date.'

To facilitate reference, I propose to call the ancient river which, it is postulated, rose in Assam and flowed into the Arabian Sea, the 'Indobrahm.' Any particular portion of it will be referred to under the name that it now bears and the area through which it runs: for instance, the Assam Brahmaputra or the Kohat Indus.

As the river in question was a result of earth-movements which took place in Tertiary times, it will be advisable to begin by glancing at the general topography of late-Cretaceous India. According to Dr. Hayden's description[1] there occurred towards the close of the Cretaceous Period a great invasion of Tibet by the sea of Western India. This sea, the Tethys, which was continuous with the Mediterranean through Afghanistan, Baluchistan, Persia, and North Africa, covered the southern and central parts of Tibet and the northern part of the present Himalaya, and reached as far as what is now the northern border of Sikkim. To the south of this sea lay the remains of the great Gondwana continent, of which peninsular India formed a part; south of that continent was another sea, one arm of which projected northwards over parts of Burma and Assam, while another indentation foreshadowed the Arabian Sea. At the beginning of Eocene times the Himalayan folding movement from the north, the Baluchistan movement from the north-west, and the Shan movement in Burma from the east, commenced to assume serious intensity.[2] The hard rigid body of

[1] S. G. Burrard & H. H. Hayden, 'A Sketch of the Geography & Geology of the Himalaya Mountains & Tibet' 1907–1908, p. 254.

[2] It is assumed that isostatic tumefaction, which was primarily responsible for the upheaval, enabled the pressure—due to whatever cause—to plicate the strata and play its part in the piling-up of the mountain-range. The direction of movement in a fold, as Mr. Oldham points out (Mem. Geol. Surv. Ind. vol. xlii, 1917, p. [282]), is a purely relative matter, one side being thrust over and the other under, in opposite directions. But the uniform consistency with which all the mountain-arcs produced by this disturbance face the same way, suggests that the folding movement, so far as the surface-rocks are concerned, was stronger in the direction of their convexities than in the opposite direction. The piling-up of the water in a circular ripple produced by the dropping of a stone therein is the result not only of pressure from the centre, but also of a resistance toward the centre. By suitable mechanical means a similar ripple could be produced by a centripetal impulse. The former kind of ripple is, however, so much more easily produced, and so much more commonly observed, that, when we meet with anything in Nature resembling a ripple, it seems natural to imagine that it is the result of a centrifugal impulse. Whatever their nature may be, it is convenient to assume that resultant movements, or impulses (as they might more aptly be termed) took place in that direction towards which the great mountain-arcs are convex. Even if we adopt this assumption, the direction of a movement is necessarily referred to in this paper in a somewhat loose way. For instance, the movement which produced the Afghanistan-Baluchistan-Persian arc system as a whole came from the north; but the component affecting Afghanistan and Eastern Baluchistan may be considered as coming generally from the north-west. Local components acted from the west, or from the north, or even from the north-east.

Gondwanaland was not conspicuously affected by this compression, but its northern margin, in an isostatic readjustment, gave way before it. Along this buckling margin, as the pressure continued, the rocks were thrust and piled to form the preliminary Himalayan chain. The greatest intensity of this impulse was, however, subsequent to the Eocene Period. This we know from the great height to which marine Eocene beds have been thrust in parts of Kashmir, for Mr. T. H. D. La Touche found nummulite-bearing strata at 18,500 feet above present sea-level in the Zanskar Range.[1] Considerable movement has taken place since the Pleistocene Period, and it is in fact more than probable that such movement is still proceeding.

An accompaniment of this intense plication and accumulative mountain-building along the northern fringe of the old continent was the production of a long belt of persistent subsidence between the mountain-range and the more central tract of the continent. The persistence of the subsidence is explained on the theory of isostasy, and was assisted by the weight of the accumulating sediments.[2] This vast trough, in which the Tertiary and Quaternary deposits were laid down, is bounded on the north by reversed faults, and may be looked upon as a faulted geosyncline, of which the southern slope, according to Mr. R. D. Oldham's convincing analysis of geodetic data, is a very long and gentle one, while the northern is steep and short.[3] It is doubtful whether this trough was appreciable before the Eocene Period, since when it has become increasingly deeper, being filled up simultaneously with accumulating sediments, until to-day its calculated depth, deduced from geodetic abnormalities, is between 15,000 and 20,000 feet.[4] It stretches from Assam to the Punjab, and in its earlier stage would have formed a natural hydrographic line. There is reason to believe that a similar trough exists along the north-and-south line of the Lower Indus. Speaking of these two great depressions, so far as their alluvial contents are concerned, Mr. Oldham says:—

'There is no reason to suppose that the two troughs are connected. Apart from the [geodetic] observations, . . . the outcrops of old rocks in the Chiniot, and other, hills which rise from the alluvium, point to the presence of a rock-barrier, stretching under the plains of the Punjab to the Salt Range and separating the two deep troughs.' (*Op. jam cit.* p. [246].)

In this great re-entrant between the Himalaya and the Afghan mountains the buckling effect which produced the two troughs seems to have dissipated itself over a much wider area, and generated, not one single connecting trough, but several shallow sub-troughs one after the other, the earlier perhaps nearer the mountains and the later more remote. As will be shown, the hydrographic line has been pushed in stages steadily towards the centre of India. Along the Himalaya, and to a less known extent along the Baluchistan Hills, these stages, we are supposing, were short and

[1] Rec. Geol. Surv. Ind. vol. xxiii (1890) p. 67.
[2] Mem. Geol. Surv. Ind. vol. xlii (1917) p. [270].
[3] *Ibid.* p. [243].
[4] *Ibid.* p. [230].

the trough deep; but in the central Punjab they were long, and the trough-area wide, shallow, and split up into a number of sub-troughs, the total breadth from Cherat to the Ghaggar channel being 300 miles. The Murree zone, the Siwalik zone of the Soan valley, and perhaps the Jhilam, Chinab, Ravi, Sutlej, and Ghaggar valleys are all sub-troughs or elements of this attenuated compound trough.

It has been established by Medlicott, Middlemiss, and others that the Tertiary foothills of the Himalaya are divisible into parallel zones separated one from the other by successive 'boundary-faults'—dislocations of a reversed nature—each of which forms a close approximate boundary of deposition as regards the zone whose northern boundary it constitutes. In other words, these 'boundary-faults' mark the northern shore of the Tertiary sea or the northern permanent bank of any longitudinal Tertiary river; north of each 'fault,' at the time of its formation, was land, drained by mountain-streams which have left little or no deposit within the mountain-area, but brought down large quantities of silt on to the plain below. In the Hazara mountains of the Northern Punjab Mr. Middlemiss showed that there were three of these faults dividing the area into four more or less defined zones, and another farther south shutting off a fifth somewhat less defined sub-zone, the Murree sub-zone.[1]

The southernmost of his Hazara zones Mr. Middlemiss called 'the Nummulitic zone,' since it consisted mostly of these rocks; its northern boundary-fault is the limiting line of their deposition, with the exception of a considerable patch of Nummulitic Limestone east of Abbottabad, which, however, is itself cut off by another 'boundary-fault' on the north-west. This Nummulitic zone it is now proposed to trace, before we attempt to reconstruct the sequence of events attending the birth and life of the Indobrahm. From a glance at a geological map (Pl. X) it will be seen that there is a continuous outcrop of Nummulitic beds extending from the Hazara hills through Kohat, Waziristan, and Baluchistan to the Sind coast. East of Hazara in the Jammu hills Nummulitic rocks again appear. Some unfossiliferous strata marked as doubtful Trias or Carboniferous by Lydekker (the Kiol beds), along the main boundary-fault of this area, I would also include with the Nummulitics. Farther south-east there is a gap until the Nummulitics of Simla are reached, and another until we come to a very thin interrupted band between Dehra Dun and Naini Tal.[2] The Simla and Dehra Dun Nummulitics consist of marine beds, and what is probably a mixture of fluviatile and salt-lake deposits. Similar alternations of lagoon and freshwater beds compose most of the upper stage of the Nummulitics of the Northern Punjab, and to a varied extent are seen among the rest of the Nummulitic belt from Kohat to Sind. But, since in every

[1] Mem. Geol. Surv. Ind. vol. xxvi (1896) p. 260.

[2] Further work may show these gaps to be shorter or non-existent.

locality nummulites are found at some horizon or other, it is unquestionable that marine conditions existed at all these localities at some time or other during the Nummulitic epoch. In the Lower Nummulitics of the Punjab are great thicknesses of massive Nummulitic limestone, and similar beds are found in the Salt Range, Kohat, the Afghan border, Baluchistan, and Sind. Now, the northern boundary of the Hazara Nummulitics we have found to be a boundary-fault or shore-line—a shore-line with an indentation east of Abbottabad, caused apparently by the obstructive stress at the Jhilam syntactical point,—and this feature has been traced westwards to the neighbourhood of Cherat. Farther west and south-west are large blanks in the geological map, but the isolated mapped areas all seem to point to a land-barrier on this side of the Nummulitic band. The rocks of Kabul belong to the ancient systems, and that there was ever connexion between the Nummulitics of Northern Afghanistan and those of the Punjab across Kabul is, I think, unlikely. The Nummulitics of Ladak in Kashmir, which include marine beds, were thought by Lydekker to belong to a separate basin of deposition, and it seems very unlikely that they were ever continuous across the enormous ranges separating them from the Jammu and Punjab Nummulitic, especially in face of the boundary nature of the fault alluded to. The occurrence at 18,500 feet in Zanskar is not more than 15 miles distant from the Ladak outcrop, while the occurrence in Hundes (Ngari Khorsum) is on the same general line of strike; both evidently belong to the Ladak exposure. Land was, therefore, probably continuous from Eastern Afghanistan through Kohistan and Kashmir, and along the line of the Himalaya as far as Naini Tal, where the Nummulitics appear to end. The Nummulitics of the Garo Hills belong to another basin: namely, the gulf which extended up from Arakan through Haflong towards Upper Assam. From the Kabul area, if we judge from the strike of the beds and the topographical features, the land-barrier probably extended to Kandahar and perhaps as far as Chagai, both of which areas have been mapped in part.

With regard to the southern boundary of the Nummulitic sea, this must be placed parallel to, and somewhere beneath, the alluvial trough along the Himalayan foot. Numerous portions of the old Gondwana continent project through the Alluvium as far north as Delhi and as far north-west as Pokaran and Bhachbar in Rajputana; but there are some small isolated inliers of Purana rocks cropping out at Chiniot, Sagla, and the Kirana Hills within 25 miles of the Salt Range. The southern coast-line may be drawn, therefore, a little north of these hills, 100 miles or so distant from the northern coast-line, approaching by degrees more closely to the latter in the direction of Simla, and meeting it in the vicinity of Naini Tal, where the Nummulitics are very thin. The Nummulitics were thus laid down in a narrow arm of the sea, or gulf. Restoring in our mind's eye the mountain-arcs to the less advanced position that they held in Nummulitic times, and obliterating or

reducing the syntactical angles which separate these arcs, we can trace this gulf from Baluchistan and Sind to Eastern Afghanistan, curving eastwards thence through the Punjab along the foot of the Himalaya as far as Naini Tal. The interruption of the outcrop between the Jammu hills and Simla, and between the latter place and Dehra Dun, must be attributed to overlap, unconformity, or faulting; but that the beds were continuous is obvious from the occurrence of nummulites in the Naini Tal Nummulitics, showing a connexion with the open sea. The Nummulitic outcrops of Bikaner and Jaisalmer may belong to the main gulf, or may indicate a small branch of it.

The Himalayan, Afghan, and Baluchistan movements, therefore, during the Nummulitic epoch drove the old Cretaceous sea westwards, Tibet and the whole of the Himalaya (with the exception of the Ladak valley) becoming dry land. They, however, assisted in producing a depression along the base of the continuous series of mountain-arcs, forming a gulf in which a constant struggle took place between the deposition of silt tending to fill up the gulf, and the general subsidence tending to deepen it. Sometimes the silting action prevailed to such an extent as to cut off land-locked salt lagoons; this process was assisted by a corrugating action, by which the floor of the gulf was folded into small anticlines and synclines, an effect quite apart from the general depression of the whole as a geosyncline, or geosynclinorium as it would be more aptly termed in places. Much of the Kumaon and Simla Nummulitic, as well as most of the Upper Nummulitic of the Potwar and Hazara, was presumably deposited in such salt-lakes and lagoons. It is, in fact, possible that at times the gulf, as a whole, was cut off from the sea. East of Naini Tal the hydrographic line was probably continued by a river draining westwards into the lagoons, the lagoons coalescing into a marine gulf once more for a short time at the end of the Nummulitic epoch. It is not proposed here to trace the oscillations which took place locally between marine and lacustrine or fluviatile conditions; but there came a time when, from Simla to the Shirani Hills, and also farther south, these oscillations ceased, and one type of deposit only was laid down to form the great Murree Series.

In the Simla area the Murrees are represented by the Dagshais below and the Kasaulis above. The latter resemble the overlying fluviatile Siwaliks, while it has been suggested that the former were deposited in salt-lakes and lagoons. Farther west there is no definite line between Upper and Lower Murrees, the one passing up into the other. The Lower are like the Dagshais, and very similar to the red clays of the Upper Nummulitics of the same area and of the Simla Subathus, for which I have proposed a similar origin; the only alternative is to regard them as fluviatile deposits. The Upper Murrees resemble a mixture of Dagshais and Kasaulis. These Murree beds have been traced through Kohat and Waziristan, but were not identified in the Shirani Hills farther south. South-west of Dera Ismail Khan, Lower Murrees (Upper Naris)

have been recognized, and are practically continuous to Sind, where they appear to be fluviatile. It is quite possible that a search for vertebrate remains in the Shirani Hills may demonstrate the presence of Murree beds, and so bridge the supposed gap in the belt of these deposits. We may then postulate either a river already established from east of Naini Tal to Sind, or, following the suggestion made above, a series of lakes and lagoons extending from Simla to the Shirani Hills, into which flowed a river from the direction of Assam, the precursor of the Brahmaputra. At the other end these lagoons were drained by a river flowing through Sind, the precursor of the Indus. Finally, towards the end of the Murree epoch, the whole line of lagoons and lakes were drained, and gave place to a river. The river connecting the old lake-system with the Arabian Sea was meanwhile submerged to form an estuary, in which were deposited the Gaj Beds of Sind. This estuary finally silted up, and at the beginning of the Siwalik epoch the whole geosynclinal line of depression was, according to the hypothesis that I am advancing, occupied by a river, the Indobrahm, rising probably in Assam, flowing north-westwards along the foot of the Himalaya, from which it received numerous silt-carrying tributaries, and emptying itself into the Arabian Sea, which at that time covered part of Sind. More will be known regarding the distance to which it extended eastwards, when the Assam Siwaliks have received more attention; but the Himalayan movements must have produced similar effects at this end of the chain, and it seems justifiable to deduce a continuation into Assam of the hydrographic line and, to some extent at least, of the trough. Mr. Oldham gives no geodetic evidence of the latter; there seems to be a slight sub-alluvial barrier between the Garo Hills and Bhutan, perhaps like that which slightly interrupts the Punjab trough as the sub-alluvial prolongation of the Aravali ridge north-east of Delhi.[1] The proximity to the Shan fold-system would explain such interferences in Assam.

Throughout the whole of the Murree epoch the buckling movement persisted, and the continued depression accompanying it permitted of the accumulation of a great thickness of sediments. This depression seems, in the Murree epoch, to have reached a maximum in the neighbourhood of the obstructive or syntactical point of Mozuffarabad, for the Murree beds are here not much less than 8000 feet thick. Another effect of the persistent movement from Eocene to Recent times was to push the hydrographic line farther southwards in the Himalayan section, and farther eastwards in the Baluchistan section. This process was assisted by the great excess of silt brought down by the drainage of the mountainous region on the north and west, over that contributed by the drainage of the land on the peninsular side. This retreat of the hydrographic line is especially marked in the large re-entrant

[1] Mem. Geol. Surv. Ind. vol. xlii (1917) pp. [243] & [245].

of the Punjab and the North-West Frontier, where the first stage was its transference from the Murree zone southwards to the Soan valley or Siwalik zone. In post-Tertiary times, as we shall see, this line was pushed still farther towards the peninsula. The relationship of the Zhob-Valley Tertiaries in Baluchistan awaits further investigation.

The Siwalik Indobrahm, therefore, rose probably in Assam, flowed along the southern border of Bhutan, traversed the northern angle of Bengal below Darjiling, skirted the southern margins of Nepal and Kumaon, proceeded north-westwards through Dehra Dun and the Sirmur State, up through the Kangra district into Jammu, thence along the Soan valley south of Rawalpindi, past Makhad, across Kohat to the Bannu plain, where it turned south past the Shirani Hills and Bugti Hills, debouching ultimately into the Sind estuary, which silted up in later Siwalik times. On its right bank it received young vigorous tributaries born in the Tertiary Era; on its left bank it received as tributaries the relics of very ancient rivers which drained Gondwanaland, such as the Son, the Chambal and its branches, and others. The Punjab Soan, as indicated above, is to be regarded as a relic of the old Tertiary Indobrahm, and is in conspicuously puny proportion to the great thickness and extent of the Tertiary fluviatile sediments through which it flows. The reasons for believing in the presence of this Siwalik river may now be enumerated :—

(1) A marine gulf originally occupied most of the same line, and during the silting process the oil and coal of this region were produced and gypsum was deposited; this hydrocarbon, coal, and gypsum belt follows the Nummulitic outcrop from Kumaon to the Mekran coast. Such a filled-up gulf is naturally followed by a river—for instance, the Burma gulf by the Irrawadi, or the Mesopotamian gulf by the Tigris and Euphrates,—which would be pushed farther towards the centre of the peninsula by the persistent movement.

(2) The supposition that the Siwalik deposits were laid down as enormous talus-fans by the mountain-streams which issued into the plain, has always been difficult to accept in view of the great thickness of the deposits—for they average over 16,000 feet—and their great extent. An almost unbroken belt of these beds can be traced, usually in great thickness, from Assam to the Soan valley and thence to Baluchistan, bounded externally by continuous mountain country consisting, where known, of igneous and very ancient rocks, with or without an intervening belt of Murree rocks. It seems far more reasonable to deduce a single river rather than a number of transverse streams. The mountain-streams, in any case, must have had an outlet to the sea in one direction or the other, and must have joined a main river in the plains.

(3) There are no grounds for assuming that the northward-flowing drainage of the old Gondwana continent was reversed in Siwalik times. In fact, the depression of the trough would have invigorated this drainage, which, it is highly probable, persists to this day. It seems almost certain, therefore, that this northerly drainage must have met the southerly Himalayan drainage in a large river flowing either south-eastwards or north-westwards. Since the Siwalik outcrop is not continuous to the sea south-eastwards, but is practically continuous north-westwards and subsequently southwards along the line of an old gulf, it seems reasonable to assume that the river followed this direction.

(4) This Siwalik belt is succeeded on the side towards the peninsula, and remote from the mountain-building, by a similar and even thicker belt of recent river-deposits, to be mentioned later.

(5) Many of the streams draining the Himalaya have north-westward pointing V's in their course where they cross the Tertiary foothills, or where they enter the plain. These are thought to indicate, according to Dr. Pilgrim's suggestion, a former north-westward-flowing main river, of which these streams were tributaries (see below).

(6) The similarity of the river-fauna in the Ganges and in the Indus points to a connexion best explained on the assumption of a large main river uniting what are now the Ganges and Indus basins (see below).

(7) The similarity in nature and strike between the Shillong Plateau and the northern region of the Indian peninsula makes it probable that they represent what was once a continuous feature, the flank of a long river-valley. It is this continuity of the physiographical and geological features along this line from Assam to the Punjab that is so striking. There is a continuous regular mountain-arc of ancient rocks on the north; there is a parallel upland of similar ancient rocks on the south, continuous beneath the presumably shallow gap between the Rajmahal and Garo Hills; between this mountain arc and the upland is a continuous outcrop of Alluvium of great maximum thickness, occupying a continuous trough, and succeeding what there is no reason to doubt is a continuous Tertiary river deposit. The sub-alluvial barrier deduced north-north-east of Delhi interrupted neither the continuity of the Siwalik deposits nor that of the Alluvium. There is no rock-barrier in the plains at the present day between the basins of the Indus and the Ganges, the watershed being a scarcely perceptible one.

(8) The two hypotheses of single westward-flowing rivers flanking the Himalayas throughout their length, one on the Indian side and one on the Tibetan side, mutually support each other, and are strengthened by the curious parallelism between the histories of these two hydrographic lines (see below).

The Siwalik Indobrahm either extended back into Assam from the beginning, or very soon cut its way back into that province. There is a short break in the continuity of the Siwalik exposure south of Darjiling, a result possibly of excessive exposure to the south-south-westerly monsoon sweeping through the Rajmahal-Garo Hills gap and causing a transgression of the Alluvium northwards sufficient to overlap locally the Siwaliks; the latter are, in all probability, continuous beneath the Alluvium. Eastwards Siwalik beds are seen fringing the plain up to the extreme point of the Assam valley. A glance at a geological map will show that the Shillong Plateau appears as an interrupted extension of Bihar, and consists of much the same kind of rocks (Pl. X). It is, in fact, part of the more central tract of the old Gondwana continent of which peninsular India consists, and geodetic observations confirm the surmise that the intervening alluvial gap made by the Ganges and Brahmaputra is of no great depth. That is to say, the southern boundary of the great trough already mentioned extends beneath this gap, and continues as the Shillong Plateau and the Mikir Hills in Assam. It seems highly probable, therefore, that the Siwalik Indobrahm extended back between Bhutan and the Shillong Plateau into Upper Assam. Here it must have come into conflict with another river which at that time flowed south-

westwards between the Shillong Plateau and Mikir Hills on the one side and the Naga Hills on the other, over what is now the hill-section of the Assam-Bengal Railway, into the Bay of Bengal. The present Meghna may be the remains of this river, which seems to have been beheaded by the Indobrahm. From the size of the Siwalik deposits in this railway hill-section, this old Meghna appears to have been a river of some magnitude, and may possibly have derived its importance from the capture of the Tsangpo, now the Tibetan part of the Brahmaputra. The Tsangpo was then much shorter than it is now, and did not reach far into Tibet; it is thought to have formed at that time the head-waters of the Irrawadi, connected therewith by what is now a tributary of the latter, the Chindwin.[1] The upper waters of the Tsangpo-Meghna were then apparently captured in turn by the Indobrahm. The Kapili tributary of the Brahmaputra seems to have cut back at some time between the Mikir Hills and the Shillong Plateau and captured a part of the Meghna, but whether this capture was effected before that made by the Indobrahm is not clear. Whether the Chindwin-Irrawadi or the Meghna were intermediaries or not, the Indobrahm—or Brahmaputra, as it may then have become—eventually captured the head-waters of a Tibetan river, the history of which is a curious one.

Sir S. G. Burrard & Dr. Hayden have pointed out the strange backward direction of many of the present Tsangpo tributaries, which is explained by the assumption that they originally fed a westward and not an eastward flowing river:—

'The most recent maps show that shortly before their junctions with the Brahmaputra, these tributaries are beginning to bend in their courses, and to turn towards the present direction of the Brahmaputra's flow.'[2]

The most important tributaries having a backward directed course are the Kyi or Lhasa, the Nyang, the Rang, and the Shang, but there are many smaller ones that exhibit the same peculiarity. The eastern end of the Himalayan chain is supposed to have begun to rise earlier than the western. This would initiate in early Tertiary times not only the Indobrahm line, but also another line of drainage in the same direction on the Tibetan side. Sir S. G. Burrard & Dr. Hayden suggest three hypotheses worthy of consideration, regarding the former outlet of this old westward-flowing Tibetan river:—

(*a*) It may have flowed over the Photu Pass and through the defile of the Kali Gandak on to the Ganges plain;

(*b*) It may have passed through the basin of the Karnali with a similar destination; or

(*c*) It may have followed the present Himalayan course of either the Sutlej or the Indus.

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[1] Until it was shown to be otherwise, the old Chinese surveyors believed that the Tsangpo of Tibet still flowed into the Irrawadi (S. G. Burrard & H. H. Hayden, 'A Sketch of the Geography & Geology of the Himalaya Mountains & Tibet' 1907–1908, p. 157).

[2] *Op. jam cit.* pp. 155–56.

It is perhaps idle to speculate far in this direction, but the following considerations are worthy of some attention. An examination of the map will show an interrupted hydrographic line from Pemakoi to Gilgit, represented at the present day by the Tsangpo (perhaps including the Raga tributary and a small branch of the Chaktak), the Manasarowar Lakes, the uppermost reaches of the Sutlej, the Indus along its Gartang channel and its tributary the Shyok, as far as Gilgit, and perhaps the Gilgit River beyond. It seems more than likely that this line was once a continuous drainage-line sloping westwards, and occupying either a geosyncline or a line of easy denudation, such as a belt of softer beds or a fault. The marine and fluviatile Nummulitics of Ladak belong to this line, corresponding in position to the Nummulitics of the hydrographic line on the other side of the Himalaya, and indicating that the Tibetan line is as old as the Indian. The Pleistocene of the uppermost reach of the Sutlej also belongs to it. Eventually, there is reason to believe, the Tibetan line was occupied by a river which rose somewhere in or near Pemakoi, and either joined the Oxus, or found its way to the Arabian Sea, independently or by way of the Indobrahm. At the present day the Indus at Bunji, where it abandons its north-westward course and turns southwards, is 3400 feet lower than the Tsangpo-Brahmaputra where it leaves the same geotectonic line.[1] From Mayum, a town above Lake Ukrang east of the Manasarowar Lakes, to Bunji, the average westward gradient is twice as steep as it is from Mayum eastwards to the point where the present Tsangpo turns southwards. In spite of its immense elevation the Tsangpo is a sluggish and navigable river south of Lhasa, and has cut no deep basin for itself in Tibet. The Indus, on the other hand, has cut its bed to a low level on the Tibetan Plateau, the fall in this part of its course being hardly more than 3 feet in a mile; across the Himalaya it has a remarkably equable and comparatively gentle fall.[2] Without attempting to guess the order in which events occurred, there are reasons for deducing:—

(1) That this Tibetan River flowed westwards and north-westwards from Pemakoi to Gilgit.

(2) That its uppermost waters were captured, possibly in turn by the Irrawadi-Chindwin and the Meghna, but finally by the Indobrahm or Brahmaputra, the capturing river at once beginning to cut back up one of its own small tributaries westwards along the already excavated channel of the old Tibetan River, capturing this channel piece by piece and its tributaries one by one, and completely reversing its drainage.

(3) That, perhaps before this struggle had proceeded far, the Kali Gandak may have captured the upper part of the Tibetan River, and have thus been enabled to scoop out the extraordinary depression of the Photu Pass, which is only 250 feet higher than the Tsangpo plains.[3]

(4) That the Sutlej effected a similar capture, part of the captured river still existing as the uppermost reaches of the Sutlej; and that the dwindling

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[1] S. G. Burrard & H. H. Hayden, *op. jam cit.* p. 171.
[2] *Ibid.* p. 171. [3] *Ibid.* pp. 147 & 155.

of the portion captured by the Sutlej, due to the advance westwards of the invading Tsangpo, is perhaps responsible for the insignificance of the present stream at the bottom of the deep cañons cut in the thick alluvial valley of Ngari Khorsum.

(5) That the Attock tributary of the Indobrahm, perhaps at an early date, captured the Tibetan River in Gilgit.

It will be seen that the parallelism between the old Tibetan River and the Himalayan part of the Indobrahm is not confined to their position and direction, but also applies to their age, origin, and history. They both appear to have supplanted marine gulfs along the western part of their courses at the same period; both seem to have been the result of the Himalayan movement, to which their courses are at right angles; in both cases the eastern half of the stream has been completely reversed in direction by capture on the part of an invading river.

As an indication of a north-westward-flowing main river along the Himalayan foot, Dr. Pilgrim cites the local **V**-shaped course of many of the present rivers from the mountains as they cross the Siwalik belt, the angle of the **V** pointing north-westwards and occurring usually close to the boundary-line between the Siwaliks and the Alluvium. The northern limb of each **V** may be regarded as the remnant of a right-bank Indobrahm tributary, which has persisted in its old westerly direction, and has become more deeply impressed and permanent owing to the upheaval of the Siwalik deposits over which it flows. The southern limb of the **V** would represent the final position which the capturing stream has taken up: for, if the deduction that the actual capture happened subsequent to Siwalik times be correct, it must have taken place within the outcrop of the Alluvial belt—that is to say, the point of the **V** at the time of capture was west of where it now is, but has since worked eastwards until it met the more stable topography of the Siwalik belt, where its regression was in most cases held up. Figs. 1–4 (pp. 150–51) illustrate this point in some of the larger rivers, showing the general westward course through the Siwalik belt and the more southerly tendency in the Alluvium; the Sutlej seems to be an exception, unless the point of the **V** has worked back into the centre of the Siwalik belt.[1]

At the close of the Siwalik and during the Recent period the left-bank affluents of the lower Indobrahm, the Jhilam, Chinab, Ravi, Beas, Sutlej, and Ghaggar (assisted perhaps by the continued earth-movements) cut back across the plains of the Punjab in a north-easterly direction, and captured various portions of the Indobrahm, perhaps approximately in the order named: not only because the distances to be cut back were in the same order, but also because the suggested geosynclines along which these rivers cut would probably be initiated in this order. Whatever the precise order was, the Ghaggar must have become

[1] The higher parts of the courses of these mountain rivers—the portions traversing the older pre-Tertiary rocks—are not relevant to this question.

Fig. 1.

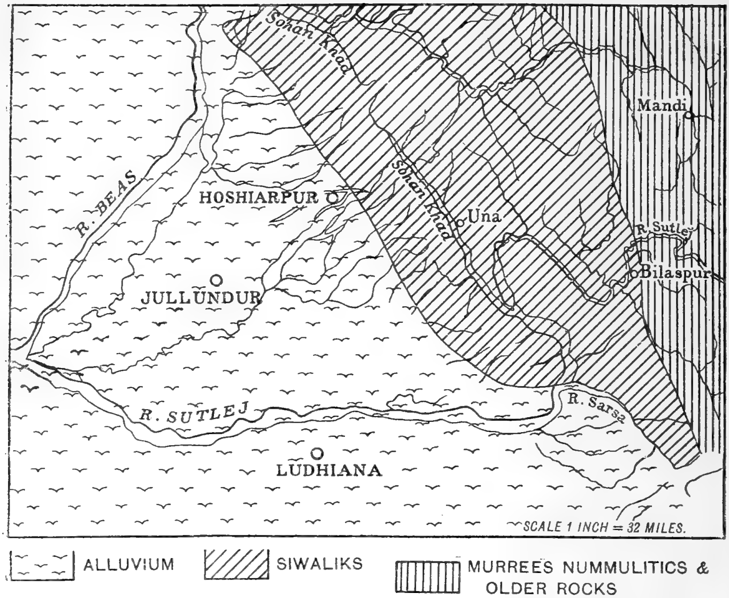
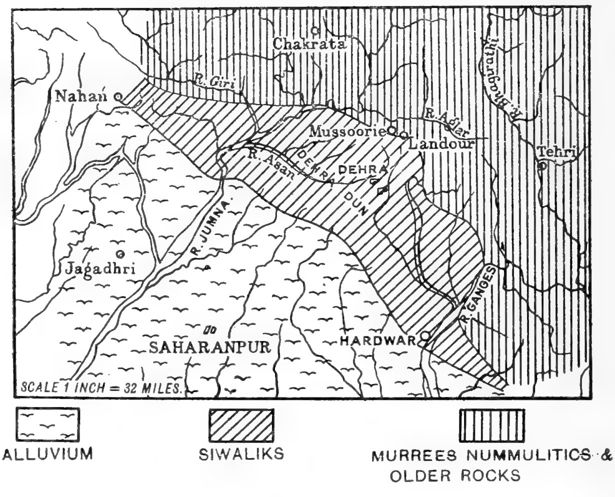

Sohan Khad
Mandi
R. BEAS
HOSHIARPUR
Sohan Khad
Una
R. Sutlej
Bilaspur
JULLUNDUR
R. SUTLEJ
R. Sarsa
LUDHIANA
SCALE 1 INCH = 32 MILES.
ALLUVIUM
SIWALIKS
MURREES NUMMULITICS & OLDER ROCKS

Fig. 2.


Chakrata
R. Bhagirathi
R. Giri
Nahan
R. Aglar
Mussoorie
Landour
Tehri
R. Asan
DEHRA DUN
DEHRA
R. JUMNA
Jagadhri
R. GANGES
SAHARANPUR
HARDWAR
SCALE 1 INCH = 32 MILES.
ALLUVIUM
SIWALIKS
MURREES NUMMULITICS & OLDER ROCKS

the final channel of the river.[1] The Upper Jhilam has the appearance of having been beheaded by the Chinab, and of having lost the importance commensurate with its valley. After the Lower Jhilam had captured the Indobrahm, what is now the

Fig. 3.

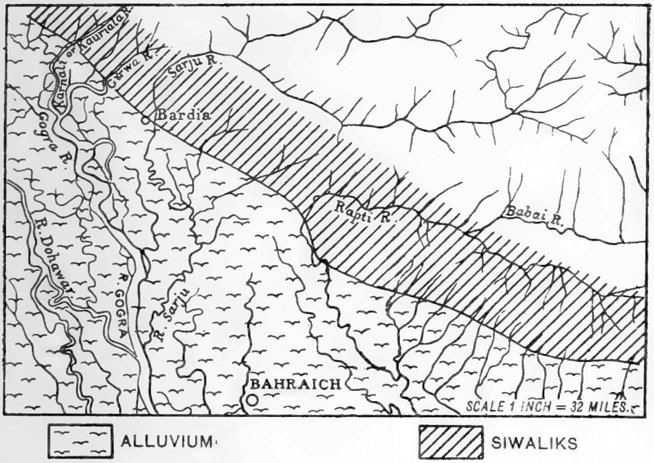
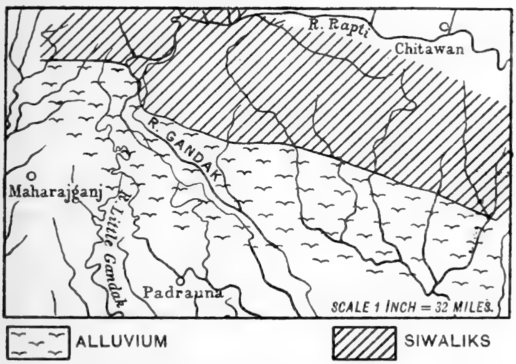



Fig. 4.




[1] The anastomosis of these Punjab rivers is and probably has been a fluctuating factor, so that the actual number of tributaries which commenced to cut back from the main river across the Punjab and Rajputana along supposed geosynclines, is a matter of pure speculation. The tributaries branched, and the geosynclines may have done the same; but their present parallelism and the general equality of their distances apart suggest that the number of these tributaries, half-way across, was five or perhaps six: four of them remain, one is a dry channel, and if a sixth ever existed farther south, no trace of it has been recorded.

Upper Jhilam must have formed a continuous tributary with the Soan, and this river was doubtless responsible for the gravels and alluvial deposits of the Soan valley, since these are rather more considerable than they would be had they been entirely due to the modern Soan. The upper part of this tributary was subsequently captured by the Lower Jhilam, and the Soan reduced to what it is at the present day.

The buckling trough-forming movement still went on during the Recent period, and enormous masses of sediment, estimated at something between 15,000 and 20,000 feet in thickness, were concentrated in this way in the central parts of the Indobrahm valley; in the lower waters deposition is thought to have been more diffuse. Across the central Punjab and Rajputana there was perhaps more than one geosyncline produced, and the deposition of sediment much less concentrated and still more widely dispersed.

While the Punjab rivers were cutting back and seizing the middle waters of the Indobrahm, its upper course was being captured, either by two branches of the same river, or by two separate rivers draining Bengal and flowing southwards into the Bay. One of these was the Jamuna or Bengal part of the Brahmaputra, and the other either a tributary of this river or a separate stream, the Ganges. These rivers present the appearance of having been initiated by the continuation northwards of the broad geosyncline of the Bay of Bengal. There is, in fact, evidence from boreholes that the deltaic area is still an area of depression. This geosyncline, the result of the Shan movement from the east, may even have been perceptible as far north as the barrier of ancient rocks which connected the Rajmahal with the Garo Hills. Perhaps with the assistance of this geosyncline, perhaps with the assistance of faults, both streams cut back through this barrier. The Jamuna captured the whole of the upper part of the Indobrahm from Dhubri upwards, and became the modern Brahmaputra. The Ganges cut back in a west-north-westerly direction, capturing element by element the succeeding portion of the Indobrahm as far as Hardwar, where the Alaknanda was captured, the Jamna at that time being the head-waters of the Ghaggar (see below). The voluminous waters of the Indobrahm having been tapped in this way, the scouring of a broad gap through the barrier was an easy matter, and the sediments derived therefrom were flung by the flood into the Bay to form the enormous delta of the Ganges and Brahmaputra. I have stated a definite case for the sake of clearness—obviously there are equally valid alternatives. It may, for instance, have been a single river which cut through the barrier, beheaded the Indobrahm, and became the Brahmaputra, the Ganges originating north of the gap as a right-bank tributary and cutting back north-westwards in the way described, the confluence subsequently retreating southwards through the gap.

The history of the Jamna may be deduced as follows. The Alaknanda, with perhaps the Bhagirathi, having been captured by

the Ganges, the present Upper Jamna and the Ghaggar or Saraswati formed a continuous single river, which probably at that date received the Sutlej also [1]; the course of this old channel can still be traced across Rajputana to the Indus, and is variously known as the Ghaggar, Hakra, or Wandan. The persistence of this river till historic times would, as noticed by James Fergusson,[2] account for the old Vedic tradition that the Saraswati was the 'chief and purest of rivers flowing from the mountains to the sea.' After the Ganges captured the eastern branch of its head-waters by means of the Lower Jamna, and the old Beas captured the western branch (that is, the Sutlej) the Saraswati became a small stream which soon lost itself in the desert of Rajputana, the greater part of its channel remaining as the dry Ghaggar or Hakra. This was the last element of the Indus captured by the Ganges, the change probably dating from historic times; in this way, as Mr. Oldham notices, the Hindu legend that it is the Saraswati which joins the Ganges at Prayag or Allahabad is founded on fact.[3] Whether there will be further invasion of the Indus basin by the Ganges is an interesting matter for speculation. There is no intervening rock-barrier to prevent it, the watershed between the two river-systems being scarcely perceptible in the plains. Geodetic figures indicate a slight rise in the floor of the sub-alluvial trough below and a little south-east of the watershed; but this apparently did not interrupt the longitudinal drainage, since the Siwalik and alluvial belts are both continuous across it. The capture of the Jamna shows that the Ganges still has an advantage in youth and vigour over the rivers of the present Indus system, and it seems not unlikely that, if not artificially controlled, it will be able to cut back farther north-westwards parallel to the trough—especially if the latter is still being deepened—and make further captures.

Mr. Oldham remarks on the suggestiveness of the fact that, in two cases where rivers have taken a different course, namely, the Saraswati into the Ganges instead of to the Indus, and the Lower Brahmaputra from its old Mymensingh course to a more westerly one, the new channel formed has been termed the Jamuna or Jamna. There is another Jamuna in Assam flowing westwards through the southern angle of the Mikir Hills into the Kapili River, a tributary of the Brahmaputra. Its history is not quite clear, but the Kapili (or Kalang, as the main affluent is called) cut back between the Mikir Hills and the Shillong Plateau, past Lumding, and may have captured part of the old reduced Meghna, after which it is possible that the Jamuna cut back farther north through a low gap in the Mikir Hills, and snatched the Meghna head-waters from the Kapili. This portion of the old Meghna valley is now drained by the Dhansiri in the reverse direction.

[1] See R. D. Oldham. 'Probable Changes in the Geography of the Punjab & its Rivers' Journ. Asiat. Soc. Bengal, vol. lv (1886) p. 322.

[2] Q. J. G. S. vol. xix (1863) p. 348.

[3] 'Manual of the Geology of India' 2nd ed. (1893) p. 450.

Mr. Sethu Rama Rau informs me that Jamna or Jamuna in Sanskrit means 'one of twins' (the feminine form since applied to a river), a not inapt name for the alternative course of a stream: in fact, for a short time, while the capture was being effected, the part captured would split into two, one part of its waters proceeding down one channel, and the other part down the other—twin rivers with a common origin. On the other hand, it may simply be that the rivers have been named after the sister to the God of Death.

There is historical evidence which makes it probable that the Sutlej and the Beas followed separate courses to the Indus not very long ago. The Mohammedan histories of the 11th and 12th centuries and the Hindu writers of Jaisalmer employ the term 'Biyah' for the combined Sutlej and Beas, now known as the Sutlej. From this Mr. Oldham surmises that the rivers must have received their actual names at a period when the Sutlej did not join the Beas, but pursued an independent course, and that it entered the Beas probably not much before the 11th century.[1] It very probably joined the Ghaggar before it was captured by a tributary of the Beas.

It is difficult to assign even approximate dates to many of the changes that have taken place. It was probably before the end of the Siwalik epoch when the Attock tributary joining the Indobrahm River near Makhad cut back into the Ladak valley. That portion of the modern Indus which runs just below Bunji, at any rate, is of no very recent construction, as shown by the colossal depth of its gorge, which is nearly 17,000 feet. The steepness and narrowness of this gorge are witnesses to its immaturity, but its immense depth and the hardness of its rocks place a limit to our conception of its youth. The Attock tributary subsequently formed part of the longest line of waterway, and, according to modern convention, now bears the name of the main river, the Indus. The desertion by the Indobrahm of its old course across the Bannu plain and the Bhattani Hills for the gap through the western end of the Salt Range at Kalabagh, may have taken place about the end of the Siwalik epoch.

Reference was made by H. B. Medlicott & W. T. Blanford, and again by Mr. R. D. Oldham, to the presence in the Ganges and Indus rivers of two closely-allied species of *Platanista*, of a very different generic type from the cetacean inhabiting the Irrawadi.[2] It was presumed that these two species were descended from a common dolphin ancestor which acquired a freshwater habitat, and indicate an organic connexion at some time between the Indus and the Ganges basins. From a note kindly supplied to me by Dr. N. Annandale, further comparison has shown that the freshwater cetacean of the Indus is absolutely identical with that of the Ganges, *Platanista gangetica* Lebeck. It is found only in the

[1] 'Manual of the Geology of India' 2nd ed. (1893) p. 450.
[2] *Op. cit.* 1st ed. (1879) p. 392; 2nd ed. (1893) p. 443.

Ganges, Brahmaputra, and Indus, and never enters the sea. The cetacean inhabiting the Irrawadi, *Orcaella brevirostris* Owen, is now known to be a marine form which makes its way for long distances up stream, not only in Burma but also in Bengal and Siam. Mr. Oldham noticed that the capture of the Upper Jamna by the Ganges provided a connexion between the Indus and Ganges basins only in the torrential regions unfrequented by such cetaceans; this difficulty, however, disappears on the assumption that, earlier than this, the organic connexion between what are now the Indus and the Ganges was a large continuous river. Dr. Annandale calls attention also to the resemblance between the Chelonia of the two rivers. He says:—

'Those of the Indus are identical with those of the Ganges, whereas those of the Mahanaddi [for instance] belong, in all cases in which they are probably known, to distinct sub-species or local races. This is particularly noticeable in the case of *Trionyx gangeticus* Cuvier, one of the commonest and biggest forms in all three rivers. I have been unable to find the slightest difference between specimens from the Ganges and from the Indus; those from the Mahanaddi (sub-species *mahanadicus* Annandale), however, exhibit distinct racial characters, not only in colour but also in the bones of the skull.'

## EXPLANATION OF PLATE X.

Geological map of the northern portion of the Indian Peninsula, on the scale of 192 miles to the inch, or 1 : 12,165,120.

## Discussion.

The President (Mr. G. W. Lamplugh) said that the Society, as well as the Author, was greatly indebted to Mr. Oldham (who had read the paper on the Author's behalf) for the lucid and interesting way in which he had dealt with it. River-capture had undoubtedly taken place in most parts of the world, and had affected small streams as well as big rivers. The process in a broad way was readily explicable, but it was difficult to understand the final stage, as the gathering-ground of the attacking stream was then reduced to its minimum while the threatened stream maintained its full strength. A temporary blocking of the main stream, or an exceptional flood, seemed to be required to give the finishing touch.

Mr. W. Whitaker asked for information as to the mechanism by which the great reversals of drainage described were brought about. How much was owing to erosion, how much to earth-movement?

Dr. J. W. Evans thought that the Author had made out a strong case for his contention that in mid-Tertiary times the rivers in the low ground at the foot of the Himalayas and in the great mid-Himalayan valley flowed towards the west-north-west, but his contention that the change to present conditions was due mainly to the working-back of the rivers at their sources was not convincing. Such action was not of great importance among really hard rocks. The variations of relative level due to earth-movements,

which must have been very considerable in the Himalayan region, probably played a much greater part.

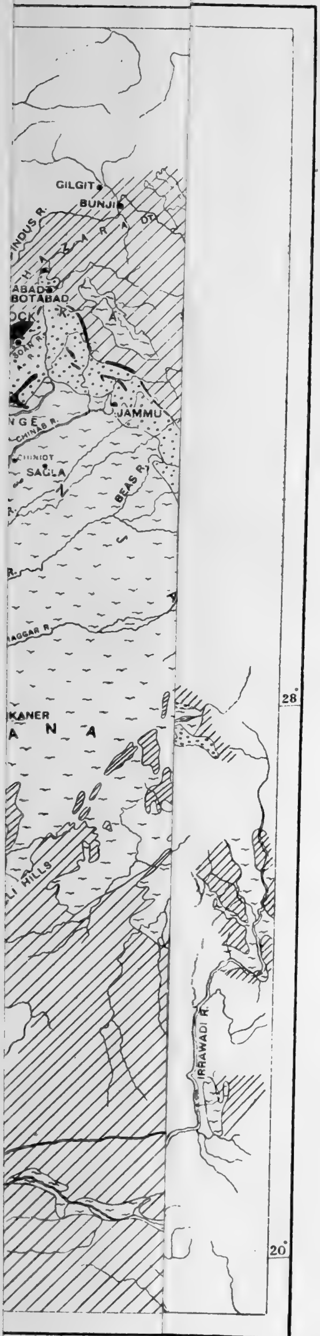
Lord Clifford pointed out that in the great waterspout flood of 1868 in the Clarence Valley (New Zealand), the water denuded the mountains of whole forests and blocked up the gorge from 80 to 100 feet high with stone and timber, creating an inland lake 13 miles long and 5 or 6 miles wide in the course of three days. It then burst away the embankment that it had made, cut 30 feet deep through the solid rock of the gorge, and carried out enough stone to reclaim 2000 or 3000 acres of a delta at the estuary of the river. When encroaching rivers cut back into the channel of a higher watershed, it was impossible to say how rapidly what looked like irresistible rock might be cut away.

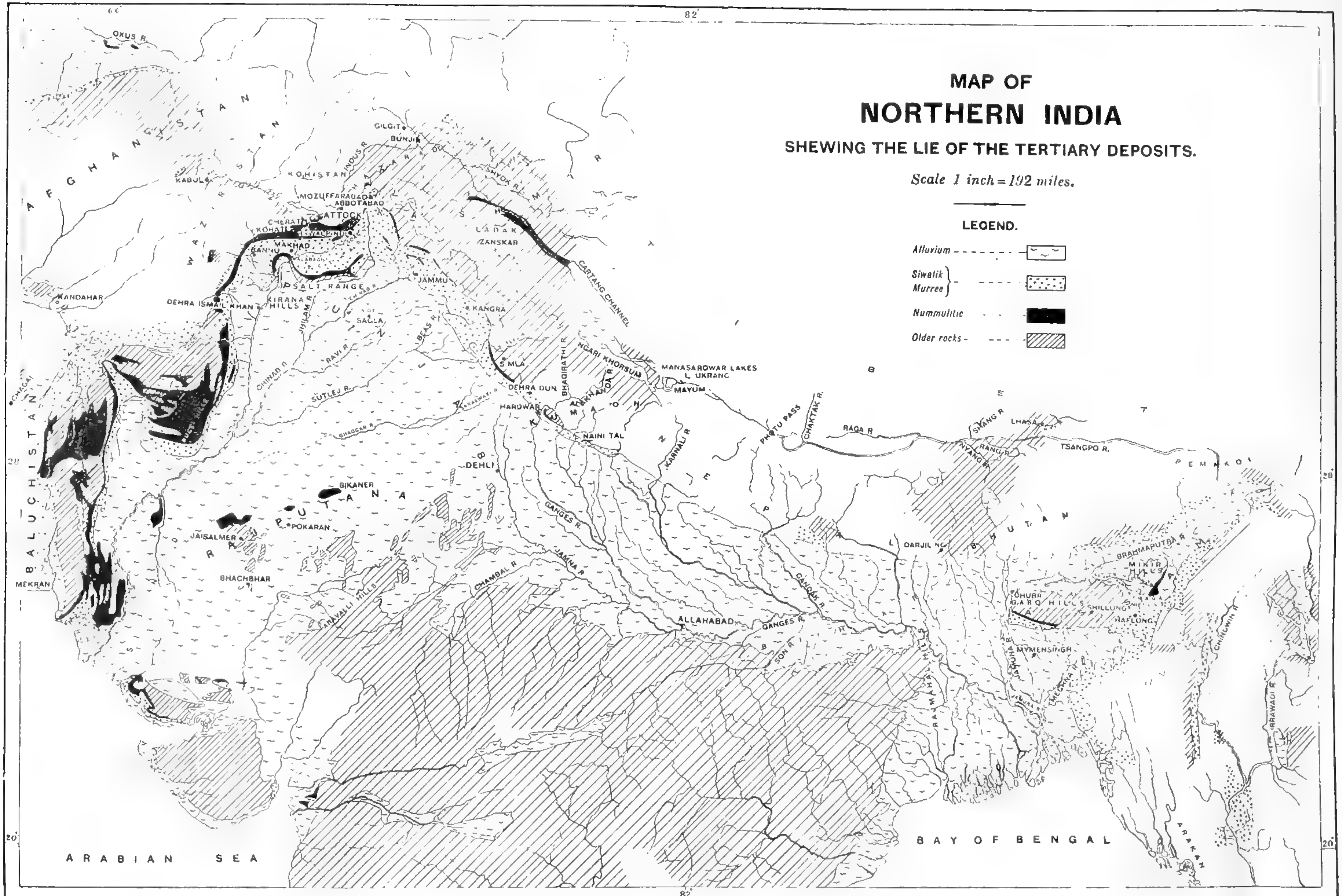
Prof. E. J. Garwood asked whether traces of hanging valleys had been observed in connexion with the westward-flowing captured tributaries described by the Author. In the case of well-known captures like those of the Albigna and Forno captured by the Maira from the headwaters of the Inn, the tributaries now entered the main stream over precipitous cliffs 1200 and 800 feet high, and similar cases had been met with by the speaker in the Tongri district in Sikhim: for instance, that of the Kang La valley. It was not necessary for the tributary to hang at its entrance into the main valley at the present time—erosion may have cut back the mouth of the tributary to accordant grade with the main valley; but it was often possible to trace the original discordance in the form of steps some distance up the tributary valleys.

Mr. G. W. Young thought the circumstance that the dolphins of both the Ganges and the Indus belonged to the same species suggested that the reversal of drainage was due to differential earth-movements rather than to capture of the head-waters of the longitudinal 'Indobrahm' by an aggressive transverse river. In the latter case the water would be gradually captured, but hardly such big and active animals as dolphins, which required considerable depth of water; whereas, if earth-movements were the cause, the same fauna would be found in both the original stream and the severed portion.

Mr. C. E. N. Bromehead wished to know whether the Author of the paper intended to imply that the capture of the 'Indobrahm,' by which it found an exit to the south and became the Ganges and Brahmaputra, was of more recent date than the capture of the river flowing north-westwards in the great depression north of the Himalayas by the southward-flowing Indus. The gorge of the Indus described in the paper was a typically new feature. If the lower course of the Ganges and Brahmaputra was also of recent date, and due to the cutting-through of a hard ridge joining the Indian Peninsula to the Assam Hills, one would expect a gorge similar to that of the Indus instead of the broad open valley which, on the map, had all the appearance of mature age.

Mr. R. D. Oldham said that, on one point, he was not in agreement with the Author. He could not regard the gaps through


GILGIT
BUNJI
INDUS R.
JAMMU
SAGLA
BEAS R.
KANER
HILLS
IRRAWADI R.
28°
20°




[For 'Abbotabad' read 'Abbottabad.]

which the Gangetic drainage reached the sea, or the rivers of the Punjab flowed to the Indus, as produced by erosion or capture in the ordinary sense. The gaps were broad and the alluvium, though doubtless shallow as compared with the depths elsewhere, still reached some hundreds of feet. He considered that these gaps were more probably due to earth-movements, by which the surface was depressed below the level of deposition; once this began, and a continuous alluvial plain was established, further changes in the courses of the rivers would result from the balance between erosion, deposition, and subsidence. He did not attach importance to the argument from the general westward trend of the valleys in the Himalayan region, because the secondary structure of the range was that of a series of secondary ranges crossing the main axis obliquely and tailing off in échelon westwards. Consequently, the general direction of the valleys may equally well have been determined by structural conditions as by the direction of the main drainage-channel. In other respects he was in general agreement with the Author's conclusions, although the exact sequence of the changes could not be determined with certainty.

The historical evidence of changes in the drainage-system was of considerable interest; but, in appealing to the ancient Hindu writings, it must be remembered that one school of Sanskrit scholars held that the composition of the Vedas antedated the Aryan invasion of India, that the prototypes of the rivers mentioned in them must be sought for in the Oxus valley, that the Saraswati of the Vedas was the Helmund, and that the names were subsequently applied to the rivers of the Punjab. In the Mahabharata, which was certainly composed in India, the Saraswati has dried up, and the legend of an underground course to the Ganges is mentioned, showing that this legend is at least a couple of thousand years old. If this interpretation is correct, no argument can be based on the descriptions contained in the Vedas; but that derived from the nomenclature of the Jumna certainly suggests that the transfer of this river from the Indus to the Gangetic system was subsequent to the introduction of the existing language into India. The Author was, however, in error in attributing this suggestion to the speaker; it is, in reality, of older date, and should be credited to the late H. B. Medlicott, although never published by him (so far as the speaker knew). The dry bed of the Lost River of the Indian Desert seems to have carried a considerable body of water at a much later date: for the chronicles of the earliest Arab invasions of India record some incidents which it is difficult to understand, unless this channel carried a large body of water so late as the commencement of the 11th century. Later chronicles equally show that it no longer flowed in the 13th century, so that the date of the final drying-up of this river can be established within fairly narrow limits; but it is not possible to decide whether the water was supplied by the Sutlej or by the Jamna.

## 9. NOTES *on the* EXTRANEOUS MINERALS *in the* CORAL-LIMESTONES *of* BARBADOS.

By Prof. JOHN BURCHMORE HARRISON, C.M.G., M.A., F.G.S., F.I.C., assisted by C. B. W. ANDERSON, 3rd Assistant Analyst, Department of Science & Agriculture, British Guiana. (Read June 25th, 1919.)

DURING the investigations of the geological structure of Barbados (British West Indies) in collaboration with the late A. J. Jukes-Browne and the late G. F. Franks, in the years 1884 to 1893, the results of which have appeared in a series of papers published in this Journal,[1] a fairly complete examination of the coral-rocks of that island was made. An earlier very accurate examination was made by Sir Robert Schomburgk, and a good account of it was given in his 'History of Barbados' (1848).

Schomburgk, as later we were, was struck with the occurrence of numerous beds of volcanic ashes characterizing the Oceanic Series of foraminiferal, radiolarian, and argillaceous deep-sea deposits so well exposed in Barbados. In the series of *Globigerina* Marls and *Amphistegina* Limestones and Basal Reef-Rocks, described on pp. 212 to 217 of the 1892 paper and on pp. 540 to 549 of the 1898 paper, fairly abundant proofs of volcanic activity in the Caribbean region during their deposition occur in the form of fragments of volcanic glass, felspar, and occasionally, though rarely, of pyroxene. But no observer found any beds of volcanic ash, or even any indication of volcanic activity, in the strata forming the coral-limestone terraces, the deposition of which probably began in the Pliocene, and certainly continued to recent geological times.

In the 1891 paper I regarded the acid-insoluble residue of the coral-rock, the analyses of which are given in that paper, as consisting only of silica with clay, iron peroxide, and alumina, these constituents varying from 0·17 to 3·10 and from 0·17 to 2·27 per cent. respectively. The analyses were all made on bulk-samples representing the limestones, and any adherent or infiltrated earthy matters contained in them. My original notes on the analyses do not show that I determined the actual composition of the fraction which I then termed 'silica and clay.'

Mr. G. F. Franks died in 1917, bequeathing his collection of rocks and rock-sections to me. On examination of his numerous sections of coral-rock, I noticed that some of them showed the presence of angular fragments of felspar, while I found but

[1] Q. J. G. S. vol. xlvii (1891) pp. 197–250; vol. xlviii (1892) pp. 170–226; vol. li (1895) pp. 313–28; vol. liv (1898) pp. 540–55; and vol. lxiii (1907) pp. 318–37.

rarely fragments of a pyroxene. A few of my own slices also indicate the presence of these minerals in the coral-rock.

The source of the red argillaceous earths which form the soils over the coral-limestones on the higher terraces (700 feet and upwards) of the island has long been a matter of interest. The red soil was described, and its origin pointed out by Jukes-Browne and myself, on pages 50 to 53 of our little treatise entitled 'The Geology of Barbados' (1890) in the following words:—

'In the coral area the most remarkable soil is certainly the red clay or loam which occurs on all the higher parts of the area. This is thickest on the very highest plateau above 900 feet, below 800 feet it is much thinner, and it does not reach below 500 feet; indeed, between 500 and 700 feet it becomes rather a yellow clay, and is in many places covered and concealed by dark carbonaceous earth, the so-called "black soil" which is black or brownish black.

'Where best developed, the red clay appears as an unctuous loamy clay of a deep red colour, or more often variegated red, yellow, and brown, and it bears a great resemblance to the red and mottled clays which are so frequently found on the Chalk districts of Southern England. The average thickness of this soil on the high ground is from 2 to 3 feet, but the surface of the coral-rock is so very uneven that the depth of the soil varies in every few yards—it fills up the hollows, and is "piped" into the holes by which this rock is honeycombed. Deep deposits of it are frequently found, and wells are said to have been sunk 40, 50, and even in one case near Castle Grant 90 feet, without reaching the bottom of such clay-filled holes. . . . . . . . . .

'With regard to the origin of the red soil, we have no doubt that it has been produced by the gradual disintegration and solution of the coral-rock itself. At first sight it seems hardly possible that the decay of a nearly pure white limestone should result in the formation of a red clay, for the coral-rock is almost entirely composed of carbonate of lime, with generally less than 2 per cent. of silica and silicates, and only a minute quantity of oxide of iron; while the red soil contains about 60 per cent. of silica and silicates, with 9 or 10 per cent. of iron oxide, and only some 2 per cent. of carbonate of lime.

'It is, however, a fact that wherever a limestone is exposed to the slow solvent action of rain-water a similar red soil is produced, and Barbadians need go no farther than San Domingo to find a case where this admits of proof, for along the western part of the south coast of that island there are raised coral-reefs covered by a similar red soil, and this soil is absolutely confined to the coral areas. Again, in Jamaica a red soil occurs everywhere over the surface of the white limestone which forms such a large part of that island.

'These red soils represent the residue of a great thickness of the limestone-rock; that is to say, they indicate the removal of a great thickness of the rock, the pure carbonate of lime having been dissolved by the rain-water which has fallen upon the surface, and has then run off or percolated through to lower levels, while the small proportion of insoluble matter has been left on the surface or swept into its hollows. This mode of origin explains the fact of the red soil being thickest on the highest levels, for it is these parts which have been the longest above the level of the sea, and which have therefore been exposed for the longest time to the action of the rain and the weather.

'Basing a calculation on the average amount of insoluble matter in the coral-rock, we find that from 50 to 60 cubic feet of such rock must have been destroyed in order to produce 1 cubic foot of the red clay, and, if we could ascertain the rate at which the destruction of the rock took place under natural conditions, we should have a basis for calculating how long it is since Barbados first rose above the waves.'

The origin of the constituents of the red earth prior to their incorporation in the coral-rock was not discussed by us. At the time we regarded the absence of defined beds of volcanic débris, such as are of very frequent occurrence in the Oceanic Series (for instance, the Conset's-Gully section supplies evidence of over fifty volcanic outbursts, each of which must have far exceeded in intensity any of the historically-recorded ones), as an indication that volcanic activity in the vicinity of the rising coral-limestone island was reduced to a minimum in that long period which elapsed from the Pliocene to geologically-speaking comparatively recent times, during which the limestones were being built up; but, in a field-address [1] on the Geological Formation of Barbados delivered in that island in January, 1908, I said:—

'Beds of volcanic dust occur at short intervals all through the Oceanic deposits and are characteristic of these strata in Barbados. I have not recognized any beds of volcanic débris in the older underlying Cretaceous and Oligocene strata or in the overlying Coralline ones. But this may be due to these being strata which were deposited in wave-and-current disturbed, shallow water, so that any volcanic dust which may have fallen on them would be widely distributed throughout them, and would not occur in thin seams as they do where they were deposited at the bottom of the calm, almost motionless, depths of the ocean.'

Soon after the eruption of the St. Vincent Soufrière in 1902, the Consulting Chemist to the Barbados General Agricultural Society, Mr. George Hughes, F.C.S., suggested that Barbados derived its soils, if not altogether, at any rate largely, from falls of volcanic dust blown over, similarly to those which had fallen in that year, during eruptions of the West Indian volcanoes, but he did not raise the question as to the origin of the acid-insoluble or weathering residua of the coral-rock.

No beds of volcanic débris have been found in the coral-limestone, nor is it probable that such beds exist. These limestones were formed, as are the coral-reefs at present encircling much of the island, in shallow water with innumerable shifting currents caused by the prevailing winds, the rise and fall of the tides and the waves, and especially the breakers of the Atlantic Ocean.

Any fall of volcanic ash, therefore, would not accumulate as a definite bed in the limestone, but its materials would be disseminated over the growing corals, the lagoon- and channel-deposits and the beach-limestones in course of formation, while by far the greater part would be washed away into the surrounding deeper waters.

Probably the most enthusiastic collector of palæontological and geological specimens who has resided in Barbados, was the late G. F. Franks. Among the specimens that Franks left to me were a series of fragments of reef-corals, valueless from a palæontological point of view; but duplicates of these he sent to Prof. J. W. Gregory in 1892, and they were described by the latter in his paper on the 'Palæontology & Physical Geology of the West Indies' [2];

[1] West Indian Bulletin, vol. ix (1909) pp. 283 & 284.

[2] Q. J. G. S. vol. li (1895) pp. 257–85.

and also many specimens of low-level beach-rock. Sir Francis Watts, K.C.M.G., Imperial Commissioner of Agriculture for the West Indies, in addition obtained for me large samples of reef-corals and of beach-rock[1] from the higher coralline limestones of Barbados. Great care was taken to ensure that the specimens were collected from positions where they could not possibly have been contaminated by the 1812, 1902, or 1903 falls of volcanic ash; while I took samples for examination of the corals and of the beach-rock from the interior of the specimens, so as to make quite certain that no contamination could have occurred in them. Quantities of 1000 grams of each were dissolved in dilute hydrochloric acid, and the residues collected for further examination. In work with Barbados rocks in 1888 and 1889 I found that very dilute, approximately deci-normal, cold hydrochloric acid has no greater solvent effect on the earthy or clayey constituents of limestone than has dilute acetic acid.

The method used was to support the fragments of limestone in a perforated shallow porcelain filtering-dish immersed just below the surface of several litres of the diluted acid which, as neutralized by solution of the calcium carbonate of the rock, received additions of hydrochloric acid in small quantities at a time, so as to keep the liquid at approximately its original degree of acidity. As the limestone slowly dissolved, its insoluble constituents gradually subsided to the bottom of the diluted acid. After complete solution of the rock was effected, the liquid was allowed to stand until it had become quite clear through the sedimentation of the insoluble residua. The liquid was decanted off, and the sediment washed with distilled water by subsidence and decantation until the acid was almost all removed. The insoluble matter was then decanted into a large, porous, alundum (fused alumina) filtering-cone, and drained. The residue was washed on the cone with distilled water until all soluble matter was removed. It was next washed off the interior of the cone by a jet of distilled water into a tared platinum basin, in which it was dried at 105° C., and weighed. The dried residua were then analysed both chemically and microscopically by well-known standard methods for such work. Excellent samples of corals and of beach-rock from the following localities were thus examined:—

**Corals.**

| *Locality.* | *Altitude in feet.* |
|---|---|
| Mount Misery (re-crystallized or calcitized coral) | about 1055 |
| Bloomsbury | ,, 1035 |
| Blackmans | ,, 900 |
| Dunscombe | ,, 850 |
| Vaucluse | ,, 731 |
| Low levels, Franks's collection—various localities | 30 to 250 |

**Beach-Rock.**

| *Locality.* | *Altitude in feet.* |
|---|---|
| Bloomsbury | about 1035 |
| Mount Wilton | ,, 937 |
| Blackmans | ,, 900 |
| Low-levels, Franks's collection—various localities | 30 to 250 |

[1] In these notes, under the term 'Beach-Rock,' I include limestones made up of reef-rocks and of channel- or lagoon-deposits, as well as actual beach-rocks.

The results of the preliminary work are shown in the following table:—

| *Specimens.* | *Extraneous matter.* Per cent. | *Mineral Residua.* Per cent. | *Organic Residua.* Per cent. | *Nitrogen.* Per cent. |
|---|---|---|---|---|
| Mount Misery coral (1) ......... | ·5993 | ·3870 | ·0123 | ·0008 |
| Other high-level corals (2)...... | ·0912 | ·0809 | ·0103 | ·0002 |
| High-level beach-rock............ | ·3338 | .3232 | ·0106 | ·0009 |
| Lower-level corals (3) ............ | ·308 | ·214 | ·094 | ·0057 |
| Lower-level beach-rock ......... | ·223 | ·184 | ·039 | ·0024 |

(1) *Eusmilia* (much altered).
(2) *Diploria*, *Orbicella*, and *Eusmilia*.
(3) *Agaricia*, *Astræa*, *Colpophyllia*, *Dendrogyra*, *Dichocœnia*, *Eusmilia*, *Madracis*, *Madrepora*, *Mæandrina*, *Mussa*, *Mycotophyllia*, *Orbicella*, *Pectinia*, and *Porites*.

Dr. F. W. Clarke, Chief Chemist, and Dr. W. C. Wheeler, of the United States Geological Survey, published in 1917 Professional Paper No. 102, giving the results of an exhaustive enquiry into 'The Inorganic Constituents of Marine Invertebrates.' They summarized on p. 12 the results of their work with massive corals as follows:—

'These analyses are remarkably concordant, and show that the stony corals contain little besides calcium carbonate. Silica and sesquioxides are probably extraneous; magnesia is altogether subordinate, although fairly regular in its amount; phosphates occur only in traces.'

From the tables of 'Reduced Analyses,' given by the authors on pp. 13 & 14, the proportions of silica and sesquioxides found by them were:—

| | *Maximum.* | *Minimum.* | *Mean.* |
|---|---|---|---|
| $SiO_2$ .......................... | ·41 | ·00 | ·132 |
| $Al_2O_3$ and $Fe_2O_3$........... | ·74 | ·00 | ·134 |

The authors deal on p. 1 with the minor inorganic constituents of marine invertebrates in the following words:—

'In a strict sense completeness cannot be claimed, even for our analyses. Minor constituents which have been detected in shells, corals, and sea-weeds, such as lead, copper, and manganese, have been ignored. They occur only in traces, and have little or no significance with respect to the larger problem before us.'

The proportions of extraneous mineral matters found by me in the fossil corals, other than the calcitic corals from Mount Misery, are very similar to the amounts of total silica and sesquioxides found by Dr. Clarke & Dr. Wheeler. The proportions found in the Barbados upper- and lower-level beach-rock, ·323 and ·184 per cent. respectively, also fall within the limits which their investigations indicate should characterize a limestone of similarly complex origin.

In order to ascertain the composition, nature, and origin of the extraneous mineral or acid-insoluble constituents of the coral-limestone, examinations, both chemical and microscopical, have been made of the residua obtained by the mode described, with the following results:—

ULTIMATE CHEMICAL COMPOSITION.

| | 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|---|
| Quartz with chalcedonic $SiO_2$ ... | — | ·06 | 2·12 | 13·06 | 20·11 |
| $SiO_2$ (organic opaline) ............ | 2·07 | 1·65 | 1·49 | 6·54 | 4·07 |
| Combined $SiO_2$ ..................... | 41·08 | 35·58 | 44·44 | 36·36 | 32·82 |
| Combined $H_2O$........................ | 11·59 | 11·87 | 9·37 | 4·82 | 8·13 |
| $Al_2O_3$.................................... | 27·47 | 27·32 | 22·03 | 16·68 | 21·38 |
| $Fe_2O_3$.................................. | 13·26 | 14·49 | 12·64 | 10·95 | 6·15 |
| FeO .................................... | ·88 | 2·24 | ·79 | 2·59 | 2·27 |
| MnO .................................... | — | ·37 | ·84 | — | — |
| $TiO_2$ .................................... | 1·75 | 2·58 | 2·00 | 1·98 | 1·52 |
| CaO .................................... | ·45 | ·21 | ·70 | 2·60 | ·20 |
| MgO .................................... | 1·44 | 1·47 | 1·83 | 1·21 | 1·39 |
| $K_2O$ .................................... | ·27 | ·59 | 1·43 | 1·09 | ·92 |
| $Na_2O$.................................... | ·39 | 1·45 | ·35 | 2·70 | ·90 |
| $P_2O_5$ .................................... | ·02 | ·01 | ·01 | ·02 | ·01 |
| Totals ...... | 100·67 | 99·89 | 100·04 | 100·60 | 99·87 |

1. Mount-Misery coral; 2. High-level corals; 3. High-level beach-rock; 4. Low-level corals; 5. Low-level beach-rock.

During the analyses the constituents of the residua which are unattacked by hot sulphuric acid were separated from those constituents which were thereby rendered soluble in dilute acids, or, in the case of silica, in a warm dilute alkaline solution. The constituents of the acid-resisting fractions are as follows:—

PERCENTAGE COMPOSITION OF THE MINERALS AND GLASS NOT DECOMPOSABLE BY HOT SULPHURIC ACID.

| | 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|---|
| Quartz with chalcedonic $SiO_2$ ... | — | 1·05 | 39·77 | 33·26 | 64·09 |
| Combined $SiO_2$........................ | 72·1 | 74·57 | 43·63 | 40·30 | 22·64 |
| $Al_2O_3$ ................................ | 6·6 | 11·13 | 8·68 | 11·05 | 6·68 |
| $Fe_2O_3$ ................................ | nil | nil | nil | 2·55 | nil |
| FeO .................................... | 5·07 | 7·56 | 4·63 | 1·63 | 1·46 |
| $TiO_2$ .................................... | nil | nil | ·58 | ·18 | ·19 |
| CaO .................................... | 9·64 | ·84 | ·39 | 3·70 | ·64 |
| MgO .................................... | 4·06 | 1·68 | 1·16 | 1·04 | 1·11 |
| $K_2O$ .................................... | 2·03 | 1·05 | ·78 | 1·35 | ·76 |
| $Na_2O$.................................... | ·51 | 2·10 | ·39 | 5·12 | ·41 |
| Totals ........................ | 100·01 | 99·98 | 100·01 | 100·18 | 99·98 |

Some, if not all, of the 'quartz' in the residua from the rocks of the higher levels is secondary chalcedonic silica, while part, if not

the whole, of that from the low-level corals and beach-rock is clastic and derived from the quartz-sand beds of the Scotland Series exposed in the eastern section of the island. The analyses have, therefore, been recalculated to eliminate the 'quartz.' The results of this are as follows:—

Percentage Composition of the Mineral and Glass Constituents other than Quartz.

| | 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|---|
| Combined $SiO_2$...... | 72·10 | 75·37 | 72·43 | 60·22 | 63·04 |
| $Al_2O_3$.................. | 6·60 | 11·25 | 14·42 | 16·51 | 18·60 |
| $Fe_2O_3$.................. | nil | nil | nil | 3·81 | nil |
| $FeO$ .................. | 5·07 | 7·64 | 7·69 | 2·43 | 4·06 |
| $TiO_2$ .................. | nil | nil | ·96 | ·27 | ·53 |
| $CaO$ .................. | 9·64 | ·85 | ·64 | 5·53 | 1·78 |
| $MgO$ .................. | 4·06 | 1·70 | 1·92 | 1·55 | 3·09 |
| $K_2O$ .................. | 2·03 | 1·06 | 1·28 | 2·03 | 2·11 |
| $Na_2O$.................. | ·51 | 2·12 | ·64 | 7·65 | 6·71 |
| Totals ...... | 100·01 | 99·99 | 99·98 | 100·00 | 99·92 |

These analyses of the extraneous mineral constituents of the Barbados limestones indicate that, in addition to ferruginous kaolin which may have been derived from extremely finely-divided clay held in suspension, or even in colloidal solution, in the ocean-waters, they contain minerals of igneous origin.

Before the detailed microscopical examinations were made, the heavy minerals, including hornblende and pyroxene, were separated from the lighter by the use of a Sonstadt solution of sp. gr. 2·90. The fragments of the lighter minerals were approximately separated into basic plagioclase, quartz, sanidine, and glass by bromoform suitably diluted with 98 per cent. alcohol. Owing to the minute size of the fragments and to the fact that many of them contained inclusions of other minerals or of gas-bubbles, it was not feasible to make these separations quantitatively.

I now proceed to describe the results of the microscopical examination of the residua.

The residua from the calcified or recrystallized coral of Mount Misery, in addition to kaolin and abundant flakes of limonite and grains of hæmatite, contain only low proportions of crystalline and glassy minerals. With the exception of some minute but perfect crystals of hypersthene, the minerals present are in sharply-angular fragments, those of glass consisting of conchoidal, very sharply-edged flakes and splinters. Very few of the fragments of felspar are of plagioclase, most of them being glassy sanidine. There are a few flakes of dark-brown biotite and some angular fragments of green and of colourless augite, and of a dark-green hornblende. A small crystal of zircon, and some minute crystalline fragments

of titaniferous iron were also found. The main part of these residua is, however, made up of kaolin and limonite. Quartz is entirely absent. The largest mineral fragments found measured in millimetres:—

| *Felspar.* | *Pyroxene.* | *Glass.* |
|---|---|---|
| ·20×·10 | ·07×·07 | ·13×·12 |

The massive corals of the higher reefs, Astræans, probably *Eusmilia*, *Diploria*, and *Orbicella*, yielded only small proportions of extraneous mineral matters. Prominent among these are small globules of non-striated felspar containing innumerable crystallites and globulites or vacuoles; a few sharply-angular minute fragments of green and of colourless augite, also of hypersthene; while sharply-angular conchoidal flakes of both brown and colourless glass are present. Quartz is present in the residua in only very small, practically negligible, proportions. Ferruginous kaolin and limonite are present in smaller proportions in these residua than in those from Mount Misery, the former containing in round figures 66 per cent. of the earthy constituents as compared with 84 per cent. in the latter. The largest mineral fragments found measured in millimetres:—

| *Felspar.* | *Pyroxene.* | *Glass.* |
|---|---|---|
| ·66×·50 | ·30×·20 | ·30×·28 |

Like the residua from the Mount-Misery calcitized coral, those from the high-level beach-rock contain large proportions of kaolinic and limonitic materials—76 per cent.—but volcanic débris is more largely in evidence. Small angular fragments of quartz are present, but not in any notable quantity. The largest fragments found are blebs of felspar, some being non-striated, others, however, showing faintly the characteristic striæ of albite, all containing innumerable globulites, vacuoles, and crystallites.

The bigger fragments generally have a less sharply-angular appearance than have those of the corals; while many of them show well-marked signs of alteration by weathering. The finer constituents are very numerous, and consist largely of colourless, brown, and dark-green glass in small, very sharply-angular conchoidal flakes and splinters, some of the larger pieces having a pumiceous structure, and containing numerous minute air-bubbles, while others show inclusions of magnetite. There are also angular and subangular to partly-rounded fragments of green and of colourless augite, and of hypersthene; a few of green-brown hornblende, very minute angular ones of sanidine, some with microlites and globulites, while some fragments of felspar show faintly the characteristics of plagioclase. Rarely a wisp of dark-brown biotite, and still more rarely a fragment of brown tourmaline. may be seen, while a fair number of fragments of magnetite, of ilmenite, of hæmatite, and, though seldom, of pyrite are found. The largest mineral fragments found measured in millimetres:—

| *Felspar.* | *Pyroxene.* | *Glass.* |
|---|---|---|
| ·65×·47 | ·18×·08 | ·25×·21 |

The minerals found in the residua of the high-level limestones indicate either an origin from outbursts of acidic volcanic rocks, such as trachyte, containing comparatively low proportions of basic plagioclases and of ferromagnesian minerals, or, more probably, are ejectamenta from sub-silicic rocks such as andesite or basalt, in which case the basic constituents have been decomposed by lateritization and weathering to form kaolin and limonite.

The extraneous matter from the low-level corals proved to be subangular grains of green augite—the characteristic one of West Indian lavas, some angular fragments of hypersthene, much plagioclase in sharply-angular fragments, a few specks of ilmenite, some very finely-divided fragments of sanidine, and a little glass in minute splinters, with much ferruginous kaolin and quartz in the proportions of 32·8 and 13 per cent. respectively. Some of the blebs of plagioclase contain minute crystals of the green augite. The larger grains of augite are characterized by the usual inclusions, some being very minute octahedra of magnetite; while some of the blebs of felspar and fragments of glass have inclusions of microlites or of air-bubbles. The largest mineral fragments found measured in millimetres :—

| *Felspar.* | *Pyroxene.* | *Glass.* |
|---|---|---|
| ·70 × ·62 | ·75 × ·38 | ·10 × ·10 |

The extraneous matter of the low-level beach-rock contains a few minute prisms of green-brown hornblende, a very few minute grains of hypersthene, some flakes of chlorite, a little plagioclase, many finely-divided fragments of sanidine, and a few minute grains of ilmenite; with kaolin and grains of quartz in greater relative quantities—52 and 20 per cent. respectively—than they are in the coral residua. The largest mineral fragments found measured in millimetres :—

| *Felspar.* | *Pyroxene.* | *Glass.* |
|---|---|---|
| ·60 × ·25 | ·53 × ·30 | ·40 × ·20 |

The mean sizes of the larger mineral fragments found in the limestone were as follows (in millimetres) :—

| | *Felspar.* | *Pyroxene.* | *Glass.* | *Kaolin and Limonite.* |
|---|---|---|---|---|
| High-level reef-corals... | ·46 × ·38 | ·14 × ·08 | ·10 × ·10 | ·07 × ·04 |
| High-level beach-rock... | ·34 × ·25 | ·13 × ·09 | ·20 × ·13 | ·06 × ·04 |
| Low-level corals ......... | ·36 × ·25 | ·25 × ·16 | ·11 × ·07 | ·06 × ·04 |
| Low-level beach-rock ... | ·21 × ·16 | ·30 × ·18 | ·27 × ·20 | ·05 × ·04 |

The majority by far of the fragments of minerals and splinters of volcanic glass in every residue examined were, however, less than ·18 mm. ($\frac{1}{140}$th of an inch) in diameter. It is noteworthy that the largest fragments of minerals and glass were found in the fossil corals, while by far the highest proportion of minute specks of minerals, and especially specks of glass, were present in the beach-rocks.

The analyses and the microscopical examinations of the residues,

both as separated from the corals of the limestones and from the beach-rocks by very dilute acid, and after treatment with hot sulphuric acid followed by a weak alkaline solution, prove that in every case the extraneous mineral constituents consist of hydrated aluminium silicate—kaolin or halloysite—usually deeply stained with limonite, flakes of orange-yellow limonite, minute fragments of red hæmatite, and many specks of minerals, felspars, and pyroxene, with flakes of both acidic and basic volcanic glass which not infrequently are enclosed and hidden in minute masses of kaolin, hæmatite, or limonite.

The fragments of minerals and splinters of glass contained in the corals are fresh and quite unaltered in appearance; they are characterized by sharply-angular outlines, and, in the case of the glass-splinters, by conchoidal fracture. Hence I regard them as being wind-borne volcanic débris which have been largely protected from weathering agencies by their enclosure in the limestone. Those in the clastic limestone or beach-rock show evidence of detrition and weathering prior to the consolidation of the limestone.

The direct microscopical examination of the residua separated from the corals and beach-rocks by very dilute acid showed that, if the examinations were not specially directed towards the search for mineral fragments, the extraneous mineral constituents would be regarded as consisting essentially of kaolin and limonite with only negligible specks of felspar and possibly of quartz.

These observations and analyses indicate that the extraneous mineral matters in the high-level limestones were derived from volcanic sources, while their limonite, kaolin, or halloysite, and secondary crystalline or chalcedonic silica, where it occurs, are the normal decomposition or weathering products of lime-soda felspars and of ferromagnesian minerals, both of which classes of minerals are present in relatively high proportions in the unaltered recent volcanic ash from the Soufrière of St. Vincent and from Mont Pelé, Martinique. The lime-soda felspars and ferromagnesian minerals are of comparatively rare occurrence in the residua of the high-level beach-rock, and hence much of them which may have originally been present in the volcanic ash has been altered into limonite, kaolin, and secondary silica by detrital and weathering actions.

The extraneous minerals in the low-level limestones are more varied than are those in the high-level limestones, and contain lime-soda felspar and pyroxene in considerable proportions; they also contain quartz in fair quantities, derived probably from the older Scotland Beds, which at the time of their formation were higher in altitude than the low-level limestones and hence were exposed to atmospheric detrition and degradation, their constituents being washed, as at present, into the surrounding sea during heavy rainfalls.

If my deduction as to the origin of the extraneous mineral constituents of the high-level limestones is correct, evidence of the present or former existence of volcanic minerals should be

obtainable from the naturally separated or weathered residua of the limestone. With this object I examined, both chemically and microscopically, a sample of deep-red clay (which I had collected in 1889 from a newly opened pot-hole in the limestone of a road-cutting at Castle Grant, at an elevation of about 1050 feet). The results of the chemical analysis were as follows:—

| | Per cent. |
|---|---|
| Organic matter[1] | 2·40 |
| Combined $H_2O$ | 7·60 |
| Chalcedonic $SiO_2$ | 7·30 |
| Organic opaline $SiO_2$ (sponge-spicules)... | 9·81 |
| Combined $SiO_2$ | 31·65 |
| $Al_2O_3$ | 23·98 |
| $Fe_2O_3$ | 13·41 |
| FeO | ·32 |
| $TiO_2$ | 2·33 |
| MnO | ·02 |
| CaO | ·08 |
| MgO | ·12 |
| $K_2O$ | ·36 |
| $Na_2O$ | ·61 |
| $P_2O_5$ | ·015 |
| Total | 100·005 |

[1] Containing $N_2$ ·097.

The high proportion of titanium oxide in the pot-hole clay indicates the source of the minerals from which the clay was derived to have been volcanic magmas, such as basalt or pyroxene-andesite. My earlier examinations of the clay did not prove quite satisfactory, as I did not succeed in breaking down the chalcedonic silica contained in it, and hence obtained only scanty indications of residual minerals. I renewed my examinations, and found that the chalcedonic silica, which was resistant to solution in a warm alkaline solution of a strength equal to 2 per cent. of sodium hydrate, dissolved fairly readily in hot 20 per cent. solution of sodium hydrate, although this liquid but partly attacked and dissolved the more robust siliceous sponge-spicules present in the residua.

Microscopical examinations proved that the resistant minerals in the residua consist of numerous minute grains of sanidine, the larger with dulled, and more or less corroded surfaces and partly-rounded outlines as if from the effects of incipient weathering; some of the felspar-fragments have inclusions of microlites or of vacuoles, while one angular fragment shows the structure of albite and some others that of microcline. In places, but rarely, minute fragments of hypersthene, of a blue-green hornblende, and of tourmaline occur; while a few small fragments and some splinters of brown and of green volcanic glass are present. The edges of the ferromagnesian minerals are so worn that some fragments are subangular. The dulled surfaces and partly smoothed-off outlines of the minerals in the pot-hole clay are those

that the minerals would have if they had been weathered out from the limestones by solution of its carbonates and thence washed into the pot-hole, and therefore confirm my views as to the origin of the clay. In the residua separated without the use of acid and alkalies many siliceous sponge-spicules and some kidney-shaped blebs of opaline silica are present. A very few minute blue specks of vivianite ($3FeO\ P_2O_5\ 8H_2O$) were detected in this residuum. The other iron minerals found in it are hæmatite and limonite, neither magnetite nor ilmenite being present. The minerals in the pot-hole clay are far more affected by detrition and weathering than are those in the residua separated chemically from the limestone.

The proportions of the unweathered and partly-weathered volcanic minerals, including the splinters of glass, can be approximately estimated from the quantities of the oxides of sodium, potassium, magnesium, calcium, iron (ferrous) and titanium, shown in the analyses of the various residua. The compositions are, in round figures, approximately as follows:—

| | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| Organic silica (sponge-spicules). | 2 | 2 | 2 | 10 | 4 | 4 |
| Quartz and chalcedony ......... | — | — | 2 | 7 | 13 | 20 |
| Kaolin ............................ | 67 | 37 | 50 | 57 | 22 | 45 |
| Limonite, hæmatite, etc. ......... | 17 | 29 | 20 | 14 | 12 | 8 |
| Volcanic minerals and glass ... | 14 | 32 | 26 | 12 | 47 | 23 |

1. Mount Misery coral; 2. High-level corals; 3. High-level beach-rock; 4. Pot-hole clay, Castle Grant; 5. Low-level corals; 6. Low-level beach-rock.

The residua, both artificial and natural, if separated from the limestone without either chemical or mechanical loss, should give rise to fertile soils of favourable physical texture and chemical composition. Many years ago I made analyses of several of the red residuary soils of the highest limestone-terraces. The mean contents of important constituents of plant-food in the residua of the limestones of the high-level terraces and in the soils lying on them are as follows:—

| | *Residua from High-level Limestones.* | *Pot-hole Clay.* | *High-level Soils.* |
|---|---|---|---|
| Organic matter.............. | 5·60 | 2·40 | 2·97 |
| $N_2$ .............................. | ·22 | ·10 | ·20 |
| CaO .......................... | ·43 | ·08 | 1·79 |
| MgO .......................... | 1·12 | ·12 | ·57 |
| $K_2O$ .......................... | ·72 | ·61 | ·42 |
| $P_2O_5$ ........................ | ·013 | ·015 | ·23 |
| The other constituents of interest are:— | | | |
| $Al_2O_3$......................... | 25·60 | 23·98 | 21·38 |
| Total iron, as $Fe_2O_3$ ...... | 14·92 | 13·76 | 12·22 |
| $TiO_2$ ......................... | 2·16 | 2·33 | 2·12 |

Resemblance in composition between the residua from the low-level limestones and the soils on them is not marked, as these soils are only in part sedentary, and hence their compositions are largely affected by detritus received from sources other than the underlying limestone.

In the high-level soils the proportions of calcium oxide are higher, and those of phosphoric anhydride far higher than in the residua. The former circumstance is of course due to some of the calcium carbonate of the limestone not having been dissolved and removed in solution, the latter to the accumulation in the soils of part of the calcium phosphate soluble in dilute acid which is a constituent of the limestone, its average content of calcium phosphate being ·027 per cent., while that of the fossil corals is only ·0017 per cent.

I have made analyses of twelve normal, unweathered samples of Barbados coral-rock. The content of insoluble mineral constituents in them was as follows:—

| *Maximum.* | *Mean.* | *Minimum.* |
|---|---|---|
| ·75 | ·36 | traces |

but other samples that I examined contained much higher proportions: for instance, 1·16, 1·84, 2·32, and 3·88 per cent. of insoluble residue; these samples, however, were not normal unaltered limestones, the high proportion of insoluble matter in them having been derived either from concentration during their weathering, or possibly from the weathering of limestones on the higher terraces while the low-level rocks were being deposited.

The magnesium oxide found in the residua does not represent all that is normally present in the coral-rock. The rock also contains a proportion of magnesium carbonate which is largely an extraneous constituent of true coral-limestone. The proportions of calcium carbonate and magnesium carbonate that I found in fourteen normal specimens of the limestone were:—

| | *Maximum.* | *Mean.* | *Minimum.* |
|---|---|---|---|
| $CaCO_3$ ............... | 97·26 | 98·29 | 99·00 |
| $MgCO_3$ ......... .. | 2·44 | 1·47 | ·57 |

or, as expressed in terms of magnesia to 100 of lime:—

| *Maximum.* | *Mean.* | *Minimum.* |
|---|---|---|
| 2·13 | 1·27 | ·47 |

The proportions of the magnesium oxide are lowest in specimens of the limestone consisting entirely of reef-corals, and highest in specimens of lagoon-deposits.

It may be of interest to place on record the complete results of my many analyses of the Barbados coral-limestones, as very few complete analyses of such limestones are available. In order to avoid the use of several decimal places, the mean compositions are expressed below in parts per million or in milligrams per kilogram:—

| | *High-level Limestone.* | *Low-level Limestone.* |
|---|---|---|
| Insoluble in weak acid : | | |
| Combined $H_2O$ | 149 | 126 |
| Organic matter [1] | 104 | 665 |
| Organic opaline $SiO_2$ | 29 | 107 |
| Quartz with chalcedonic $SiO_2$ | 33 | 325 |
| Combined $SiO_2$ | 818 | 691 |
| $Al_2O_3$ | 442 | 375 |
| $Fe_2O_3$ | 249 | 174 |
| FeO | 20 | 47 |
| MnO | 15 | — |
| $TiO_2$ | 40 | 35 |
| CaO | 12 | 30 |
| MgO | 34 | 25 |
| $K_2O$ | 24 | 20 |
| $Na_2O$ | 11 | 37 |
| $ZrO_2$ | trace | |
| $P_2O_5$ | 0·2 | 0·3 |
| Soluble in weak acid : | | |
| $Ca_32PO_4$ | 280 | 201 |
| $CaCO_3$ | 983,607 | 981,782 |
| $MgCO_3$ | 14,133 | 15,360 |
| | 1,000,000·2 | 1,000,000·3 |
| [1] Containing $N_2$ | 5·8 | 10·7 |

The proportions of the extraneous mineral fragments which I was able to separate from the limestone in recognizable crystalline and glassy forms were very small, the yields per kilogram of the limestone being as follows :—

| | *Milligrams.* |
|---|---|
| High-level coral, Mount Misery | 118 |
| High-level corals | 45 |
| High-level beach-rock | 105 |
| Low-level corals | 560 |
| Low-level beach-rock | 210 |

The fact that such minute proportions can be readily isolated from a limestone and more or less exhaustively examined, both chemically and petrographically, is of interest. The present work has proved that during the long period in which the Barbados coral-limestones were being deposited there were active volcanoes in the West Indian Province, and indicates a mode of enquiry which may give valuable results (in cases where beds of volcanic tuffs are not present in limestones) in proving the existence of contemporaneous volcanic activity. Possibly this study of the extraneous mineral constituents of the Barbados coral-rocks may lead to similar examinations being made of British and other limestones, as additional to the excellent studies by Mr. E. B. Wethered of the insoluble residues of the Carboniferous Limestone Series at Clifton,[1] of the Inferior Oolite of the Cotteswold

[1] Q. J. G. S. vol. xliv (1888) p. 186.

Hills,[1] of the Devonian Limestones of South Devon,[2] and of the Wenlock Limestones,[3] as well as the searching enquiry by Joseph Lomas into the inorganic constituents of the Crag.[4] These earlier studies dealt mainly with limestones containing relatively high proportions of extraneous constituents, but were not quantitative; the present one indicates that, even where the extraneous constituents are present in relatively small amounts, the enquiry can be readily made a quantitative one in determining the various minerals present in minute amounts.

## The Presence of Titanium Oxide in the Mineral Residua.

In the analyses quoted in these notes titanium oxide is invariably shown. In the course of the earlier work done by Jukes-Browne and myself on the 'Composition of some Oceanic Deposits,' I did not determine the titanium oxide in the samples examined, our main object being a comparison of the Miocene oceanic deposits of Barbados with recent oozes obtained during the *Challenger* Expedition. Hence in analyses quoted in them, as in the *Challenger* Report on Deep-Sea Deposits, the titanium oxide was not separated from the alumina.

I have recently determined the proportions of titanium oxide in the samples of Barbados Oceanic Clay and of deep-sea dredgings (all dried at 110° C.) to be as follows:—

BARBADOS OCEANIC DEPOSITS.

| *Deposits in descending order.* | $TiO_2$ *per cent.* |
|---|---|
| 1. Volcanic mudstone (highest stratum). Oceanic deposits. | 2·85 |
| 2. Creamy white Oceanic Clay ... | 2·92 |
| 3. Creamy yellow do. ... | 3·63 |
| 4. Mottled pink and yellow Oceanic Clay ........................ | 3·30 |
| 5. Bright red Oceanic Clay ...... | 3·59 |
| 6. Dark chocolate-red Oceanic Clay ........................ | 5·73 |

| *Stations,* Challenger *Dredgings.* | $TiO_2$ *per cent.* |
|---|---|
| 186 Atlantic Red Clay, 2740 f.... | 1·92 |
| 256 Pacific Red Clay, 2950 f. ... | 2·01 |
| 224 Do. *Globigerina* Ooze, 1850 f. ........................ | ·08 |
| 238 South Atlantic *Globigerina* Ooze, 1990 f.................. | ·11 |
| *Buccaneer* Expedition, 1885, South Atlantic *Globigerina* Ooze, 1845 fathoms. | ·23 |

It is evident that the deep-sea clays forming the highest beds in the Barbados Oceanic Series were derived from volcanic débris, of lavas such as pyroxene-andesite or basalt, containing relatively high proportions of ilmenite or of a titaniferous magnetite. On the other hand, the volcanic débris in the lower ash-beds of the series are mainly persilicic and pumiceous, and hence derived from rhyolitic or trachytic magmas.

[1] Q. J. G. S. vol. xlvii (1891) p. 550.
[2] *Ibid.* vol. xlviii (1892) p. 377.
[3] *Ibid.* vol. xlix (1893) p. 236.
[4] *Ibid.* vol. lvi (1900) p. 738.

## 10. *On a* Deposit *of* Interglacial Lœss, *and some* Transported Preglacial Freshwater Clays *on the* Durham Coast. By Charles Taylor Trechmann, D.Sc., F.G.S. (Read December 18th, 1918.)

Contents.



### I. Introduction.

The object of this paper is to describe some phenomena connected with the earlier Glacial deposits that are exposed on the Durham coast. The beds to which attention is more particularly directed form part of, or are connected with, a recently-discovered deposit of Scandinavian Drift. They comprise the following:—

(1) A bed of material that, in chemical, physical, and stratigraphical characters, presents every appearance of complete identity with the true lœss of the European Continent.

(2) Some deposits of brown, grey, and bluish clay containing a varied assortment of organic remains, including shells of non-marine mollusca, ostracod valves, mammalian bones and teeth, trees, seeds, mosses, and other plant-remains: the whole having been transported by the advancing Scandinavian ice-sheet.

Both the above-mentioned deposits, in common with other phenomena connected with the earliest advance of the Scandinavian ice-sheet, are preserved in Preglacial hollows, valleys, and fissures in the Magnesian Limestone. All of them are earlier than, and completely underlie the later local Glacial accumulations, to which I gave the appellation of Main Drift, and containing local English and Scottish erratics. These erratics are completely

wanting in the underlying earlier deposits with which this paper deals.

A few words in recapitulation of matter already published[1] are necessary, in explanation of the peculiar features and mode of occurrence of the bed of Scandinavian Drift which is exposed on the Durham coast. Up to the year 1914, when I investigated and described this bed, Scandinavian boulders had never been traced with certainty *in situ* in Great Britain north of Yorkshire or north of the River Tees. Their occurrence had been certainly from time to time suggested, but they had not been satisfactorily distinguished from the ballast-carried Swedish and Baltic rocks that occur plentifully scattered on the beach on parts of the coast, especially in the neighbourhood of the great shipping centres.

The main drifts are not dealt with in this paper, except to be mentioned in the section where the possibility of Interglacial episodes is discussed, and in the attempted representation of the sequence of Glacial events in the district.

I must express my great indebtedness to the following experts, for the assistance which they have kindly afforded to me in identifying the organic remains:—Mrs. E. M. Reid, Mr. H. N. Dixon, Mr. A. S. Kennard, Mr. B. B. Woodward, Dr. C. W. Andrews, F.R.S., and Mr. M. A. C. Hinton.

## II. Description of the Bed of Lœss.

The Scandinavian Drift of the Durham coast is represented by a bed of material which is preserved in a small, Preglacial, valley-like depression eroded in the Magnesian Limestone. At the bottom of this old valley occurs a fissure of unknown depth filled with the same material. The stony and shelly clay filling the fissure and the bottom of the valley is sometimes well exposed on the foreshore between tide-marks, where it passes out to sea. A small Postglacial ravine (called Warren-House Gill) has been superimposed on the site of the old Preglacial valley, and cuts down through the overlying main Cheviot Drift and partly also into the underlying Scandinavian Drift.

In a former paper dealing with this deposit I gave a diagrammatic sketch of the section, and therein described and indicated the position of various Norwegian boulders that occur *in situ* in the cliff, or lie washed out and exposed on the shore. In describing the section I also made the remark that in parts, but especially towards its southern limit, the upper portion of this drift consists of a bed of pale-brown material full of rounded concretions, that this bed reaches a thickness of 6 feet or more, and is almost devoid of stones, though it contains occasional layers of coarse sand.

The idea that this pale-brown material with concretions might in reality be a bed of the true lœss did not occur to my mind

[1] C. T. Trechmann, 'The Scandinavian Drift of the Durham Coast, &c.' Q. J. G. S. vol. lxxi (1915) pp. 53–82.

at that time, and consequently I did not make an exhaustive examination of it.

About two years later, while I was reading a description of the Continental lœss, the similarity of the bed associated with the Scandinavian Drift of the Durham coast to that deposit was forced on my mind, and I paid several visits to the coast in order to observe it more closely, bringing some samples of it away for microscopic and chemical examination. Its similarity to beds of lœss that I had seen in New Zealand also occurred to me.

The following are the results of my continued examination of this deposit:—

As already stated, it is of a pale-brown or fawn colour, and attains a thickness in the cliff-section of 1 to 10 or 12 feet.

That portion which I regard as undisturbed lœss occurs where the surface of the Magnesian Limestone begins to rise at the south side of the old Preglacial valley, and rests directly upon the underlying rock. It appears to have been banked up against the northward facing slope on the southern edge of the old valley, presumably through the action of wind. The genuine undisturbed lœss has a thickness of about 6 feet at this point. It seems to be absent from the corresponding northern slope of the old valley. It passes upwards into a deposit consisting of lœss that has evidently been redeposited to some extent by water, shows considerable evidence of horizontal bedding, and has seams of sand, fine gravel, and occasional small boulders in it.

As already stated, the undisturbed lœss occurs towards the base of the section. It is a homogeneous bed, generally shows no trace of stratification, and, unlike the redeposited material overlying it, a fragment if detached cannot be broken along any definite horizontal plane. On the contrary, it betrays a very distinct tendency in the cliff to break down along vertical clefts and cracks. The concretions occur more or less throughout this bed, but become more numerous towards the base, although they are rather sparingly and irregularly distributed. They are all more or less elongate-oval in shape, though some are nearly spherical, and measure about 3 to 4 inches in length (see fig. 1, p. 178). In some layers they tend to coalesce one into the other, often forming structures like the so-called 'lœss-dolls' of the Continent.

Some are barely consolidated, while others are quite hard in the inner portions, requiring a blow of a heavy hammer to break them, when the interior is found to be very dense, and to contain cracks and spaces which are often partly occupied by a few calcite-crystals.

The bed of undisturbed lœss containing the concretions is very uniform in general colour and appearance, though samples of it taken within a short distance one of the other show that the relative proportion of the chief constituents which compose it varies to some extent. It is quite devoid of sand or stones, and I found no trace of shells or other organic remains in it.

Although it agrees so closely in chemical and mineralogical

composition with at least one typical sample of Continental lœss, it differs in the absence of the land shells and the tubular calcareous vegetable structures that often characterize the lœss of Europe. However, the sample preserved on the Durham coast is so small and limited in extent that this difference may not be of serious import, besides which the prolonged weathering and decalcification that it has undergone may have dissolved out any land shells or calcareous tubules (if such were originally present in it).

The surface of the Magnesian Limestone immediately underlying it is often rubbly, and is fissured and cracked in places. The surface is covered, and the cracks are filled with rubbly limestone, small Scandinavian stones, cracked flints, and rounded sand-grains, and the whole mass to a depth of 10 feet or more in the cracks is strongly calcreted, the cementing material having probably been derived from the overlying lœss.

The upper part of the section, which consists of lœss disturbed and redeposited by water, is devoid of the calcareous concretions.

A layer of this material about 2 feet thick covers the Magnesian Limestone at the top of the cliff for some distance south of the old Preglacial valley, and in this was found the big boulder of titaniferous syenite (presently to be described) which showed so much surface-decomposition.

In the old Preglacial valley south of the fissure, exposed on the foreshore and in the fissure itself, the Scandinavian Drift in its upper part is considerably commingled with yellow redeposited lœss containing streaks of sand and pebbles, Scandinavian stones, and bits of flint and chalk and marine shells. This seems to show that the Scandinavian ice-sheet advanced somewhat slowly and intermittently: also that lœss was deposited round its edge during its advance, and was overridden and incorporated with the Drift. The main mass of the lœss, however, was banked up against the southern slope of the old valley, and upon the stony and shelly clay, after the Scandinavian ice-sheet had begun to retreat.

I have not found any definite trace of lœss in connexion with the red fissures containing freshwater clay and vegetable matter presently to be described.

## III. Chemical and Mineralogical Composition of the Lœss.

The material is extremely fine, and when dry can generally be crushed between the fingers, when it falls to a very fine dusty powder. Samples riddled through a sieve of 240 meshes to the linear inch left a residue on the sieve of, in one case, 3·26 per cent., and in another case of only 1·29 per cent.

A sample of lœss from Kreuzberg, near Bonn, belonging to the Geological Collection of the Armstrong College (Newcastle-upon-Tyne), was similarly riddled, and left a residue of 3·95 per cent.; consequently, the residue of the Durham lœss amounts to less than that of the Continental sample.

A sample of the grains of the residue of more or less uniform size which remained on a 240-mesh sieve, but passed a 200-mesh sieve, was examined under a microscope.

The Durham samples showed angular quartz-grains of all shapes and sizes, the angles scarcely if at all rounded. Mica-flakes were very plentiful, and on the washed surface of some of the concretions they were seen to be arranged in all directions indiscriminately. A residue of another sample showed flakes of light and dark mica and little masses of calcreted lœss, together with the angular sharp quartz-fragments already mentioned. The residues of the Bonn lœss showed angular quartz-grains, with the edges and corners slightly rounded off. Mica-flakes were not very plentiful, but fragments of land shells, tubular calcareous structures, and bits of vegetable matter were present. These, however, do not occur in the Durham lœss.

Except for the presence of terrestrial shells in the former, the Bonn lœss and the Durham lœss are very similar in colour and porosity, and the appended series of analyses show that the Bonn material closely resembles in chemical composition some portions of the lœss of the Durham coast.

I analysed three samples of the Durham lœss, taken from the lower undisturbed portions in the cliff-section containing the concretions, within a few yards of one another, and made an analysis of the inner portion of one of the hard calcareous concretions. For comparison, I also made an analysis of the above-mentioned lœss from Kreuzberg, near Bonn.

| | *Lœss from Durham Coast.* | | | | *Lœss from Bonn.* |
|---|---|---|---|---|---|
| | *Lœss I.* Per cent. | *Lœss II.* Per cent. | *Lœss III.* Per cent. | *Lœss Concretion.* Per cent. | *Lœss.* Per cent. |
| $SiO_2$ ......... | 64·87 | 65·42 | 66·33 | 41·45 | 63·65 |
| $Al_2O_3$ ...... | 2·57 | 9·21 | 9·86 | 2·57 | 5·16 |
| $Fe_2O_3$ ...... | 5·15 | 5·45 | 5·33 | 4·11 | 5·37 |
| $CaCO_3$ ...... | 17·66 | 11·98 | 9·04 | 44·25 | 18·28 |
| $MgCO_3$...... | 3·76 | 6·02 | 5·40 | 7·00 | 4·48 |
| $K_2O$ ......... | 2·49 | not estimated | not estimated | not estimated | 1·93 |
| $Na_2O$ ...... | 1·65 | ,, | ,, | ,, | 1·45 |
| Water ...... | 1·06 | 0·29 | 0·93 | 0·55 | Trace |
| Totals ... | 99·21 | 98·37 | 96·89 | 99·93 | 100·32 |

In all the samples of the lœss the silica is high, and seems to vary but slightly in amount, except in the concretions, where of course its percentage is reduced. The alumina varies to some extent: in some places it is low, and in others rather high, reaching nearly 10 per cent.

The iron, which is completely oxidized, is comparatively high in all samples, and seems constant in quantity. The lime appears to be present as very finely-divided calcite, is variable in amount,

and of course in the concretions rises considerably in quantity. The magnesia is rather high, and may have been partly derived from some of the local Magnesian Limestones, but in the Bonn sample I also found it to be relatively high. Alkalies were determined in two samples and found to be rather high, probably owing to the quantity of mica in the material.

Fig. 1.—*Lœss concretions, Warren-House Gill (one-half of the natural size).*

Compared with water-deposited and Glacial clays from this district which I have analysed, the Durham lœss is noticeable in physical characters by its absence of plasticity, its porosity and light colour, and in chemical composition by its richness in silica and calcium carbonate and its poverty in alumina.

## IV. Notes on the Scandinavian Boulder-Clay at Warren-House Gill.

During the winter of 1917–18 the Scandinavian Drift was well exposed for several weeks on the foreshore between tide-marks along nearly the whole quarter of a mile of the section, and on the occasion of one particularly high tide the base of the cliff-section was washed perfectly clean for almost the whole extent, when the undulating line of junction of the Scandinavian with the overlying Cheviot Drift could be very well seen. A few days later, however, heavy rain washed the slipped clay from the cliffs above over it again, and the section became more obscure than it was before.

In the cliff-section the contortions of the upper layers of the Scandinavian clay and of the redeposited lœss-like material, caused

by the later ice that flowed over it, were well exposed, and recalled some sections of contorted Drift that I have seen in East Anglia.

On the foreshore a great selection of Norwegian stones was seen sticking out of the surface of the hard grey shelly clay, together with splintered flints, bits of chalk, and angular pieces of Permian limestone recalling the concretionary beds of the Upper Magnesian Limestone, but not entirely to be matched with any bed that I know in the Durham area. Several masses of red and green marl identical with that which occurs in fissures north and south of the Scandinavian Drift, indicated that the material filling them was transported by the same agency as that which carried the Scandinavian Boulder-Clay.

I collected a large series of the more peculiar erratics of Scandinavian origin, and these should, if possible, be examined by some authority who is well acquainted with the rocks of South Norway. The more characteristic rock-types are easily recognized, and in my former paper I gave a list of percentages of the different varieties that occur in this clay. Subsequent collecting tends to confirm the rough estimate that I gave then, and to support the South Norwegian origin of the whole series.

Fragments of dark limestone, apparently Norwegian, occasionally occur, but only in very small pieces; one of these contained a few specimens of a small *Orthis*-like brachiopod.

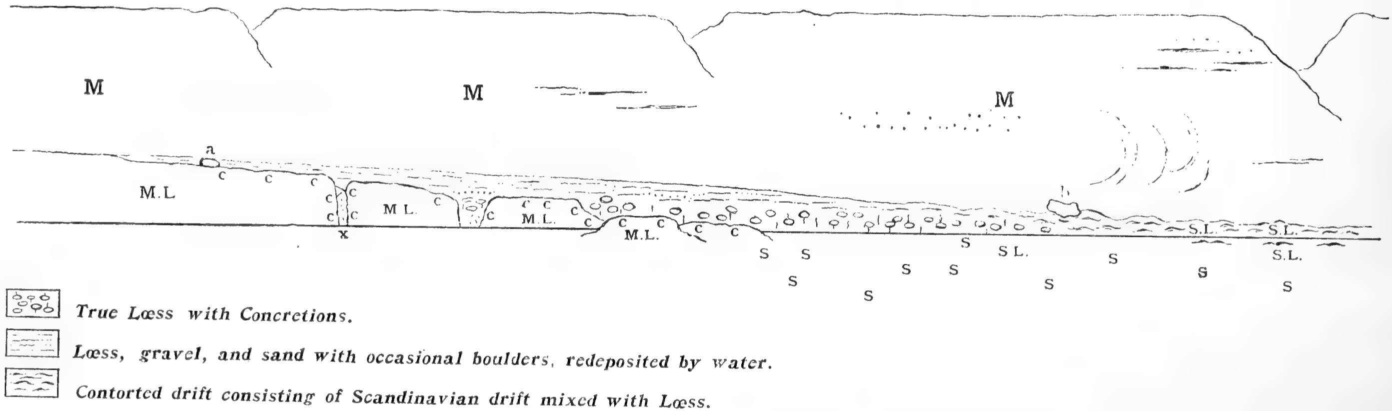
With regard to fossils, other than Pleistocene shells, the only specimens that have occurred are a fragment of a belemnite and a piece of white limestone, probably of Tertiary age, containing a few obscure gasteropods.

A few additional species of Pleistocene shells have been found, the chief among these being *Cardium edule* Linnæus, and the interesting American species *Cyrtodaria siliqua* Spengler. I have also succeeded in obtaining some perfect valves of *Cardium islandicum* Linnæus, by carefully collecting and joining together again the fragments of more or less crushed specimens that occur in the clay.

Near the base of a fissure marked *x* in fig. 2 (p. 180), I was fortunate in collecting some mammalian bones. They occurred among rubbly calcreted Magnesian Limestone, with small fragments of Scandinavian stones among it. The fissure near the base of which the bones occurred, is overlain by lœss-like Drift, and so the bones are earlier than the Scandinavian Drift, and agree in this respect with the bones of *Elephas* and rodents found in the red fissure 2 miles away to the south. There is nothing, however, to show that they are of exactly the same age, and, as they are quite unworn and unscratched, they cannot have been glacially transported for any great distance with the limestone-fragments among which they occurred.

They may have lain in a small fissure or rock-shelter (near the spot where they were found) which had collapsed or had been crushed into the fissure under the weight of the advancing ice-sheet. They consist of two astragali and a fragment of a

Fig. 2.—*Diagram of part of the Durham coast at Warren-House Gill, showing the southern half of a Preglacial valley in the Magnesian Limestone filled with shelly Scandinavian Boulder-Clay, overlain in part by lœss with calcareous concretions, which is in turn overlain by lœss, gravel, and sand, partly redeposited by water. The Main Cheviot and Northern Drift is superimposed upon all these earlier Glacial deposits.* [*Total length of section = about 220 yards.*]




M.L. = Magnesian Limestone, fissured in places.

CCC. = Rubbly surface of the Magnesian Limestone, bearing small Scandinavian stones cemented by calcareous material leached out of the overlying lœss. This brecciated and recemented rock fills up fissures, near the base of one of which ($x$) some mammalian bones occurred.

SSS. = Shelly Scandinavian Boulder-Clay with Norwegian erratics and marine shells, exposed on the foreshore and at the base of the cliff.

SL. = Contorted Drift, consisting of Scandinavian stony clay mixed with lœss.

MM. = Main local Cheviot and Northern Drift, with contortions and local red sandy patches.

*a* = Boulder of Norwegian titaniferous syenite, embedded in redeposited lœss-drift, and much decomposed.

*b* = Boulder of Carboniferous Limestone belonging to the local Drift, partly driven into the Scandinavian Drift.

limb-bone. Dr. C. W. Andrews, F.R.S., has kindly examined these bones for me, and reports as follows:—

'The smaller of the two astragali is either that of a fallow deer or of some closely-allied species (for instance, *Cervus browni*). The other also belonged to a deer about as big as the red deer, but does not seem to agree exactly with it. I am afraid that no more information can be extracted from the bones, for astragali of this group are all very much alike. The little fragment is undeterminable.'

## V. The Freshwater Shelly Clays with Plant-Remains, Mammalian Bones, etc.

In my account of the Scandinavian Drift of the Durham coast I described some fissures filled with red mottled sandstone, variegated green and grey marl, peaty wood, and other materials, and gave reasons for concluding that this material had been carried along the fringe or margin of the first ice-sheet that advanced upon the East Coast of England, namely, that which transported the Scandinavian erratics at Warren-House Gill.

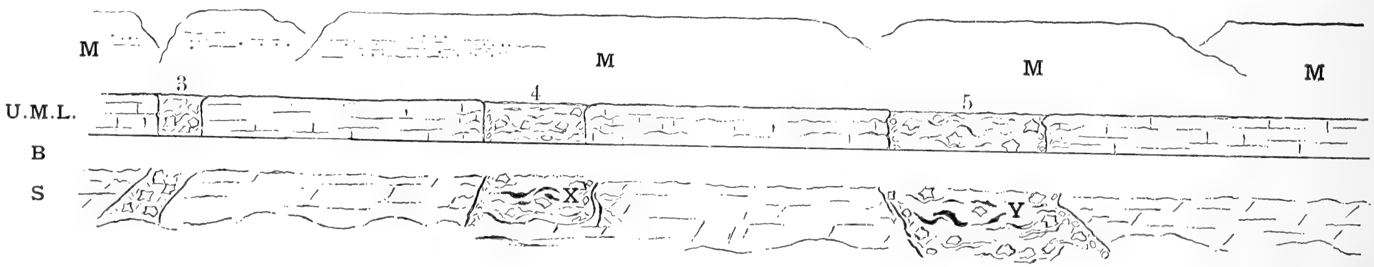
I described each of the more important of these fissures, and marked the position of ten of them on a glaciological map of the district. They occupy a stretch of about 6 miles of the coast, and the true Scandinavian Drift with marine shells occurs about the central point of this stretch of coast.

Two of the fissures south of the Scandinavian Drift were particularly well exposed last summer between tide-marks on the foreshore, and in the bottom of these I found a considerable quantity of grey and brown freshwater clay which contained a varied assortment of organic material comprising a fairly large series of species of non-marine mollusca, very plentiful carapaces of ostracods, peaty trunks of trees, mosses, seeds, and other plant-remains, together with bones of small fishes, and a few scanty mammalian bones. The latter include, up to the present, only teeth and skull-fragments of a rodent and some elephant-bones.

It is noticeable that in these two fissures the above-mentioned clays with organic remains occupy only the lower part of the fissure where it occurs on the foreshore, and are not seen in the section in the cliff, which is filled solely by crushed red and grey Permian marl and big angular masses of Magnesian Limestone. The last-mentioned materials, however, occur plentifully mixed up with the freshwater clays between tide-marks, but occupy chiefly the part adjacent to the sides of the fissure or hollow into which the material has been thrust.

The two fissures to which I refer are adjacent one to the other, occurring about 2 miles south of Warren-House Gill, and are immediately north of a footpath that leads down to the coast from Blackhall Colliery. They are marked by the Nos. 4 & 5 on the diagrammatic sketch of the shore-section (fig. 3, p. 182), the numbers being the same as those on the glaciological map of the district already mentioned.

Fig. 3.—*Diagram of part of the Durham coast opposite Blackhall Colliery, showing fissures in the Magnesian-Limestone cliff filled with large angular masses of Magnesian Limestone, Permian red and green marl, etc., and their continuation on the foreshore between tide-marks, where, in addition to the above-mentioned material, two of them (Nos. 4 & 5) contain transported slickensided clays and marls enclosing freshwater mollusca, peaty wood, and tree-trunks, seeds, ostracod valves, etc., also occasional mammalian remains. All these deposits are overlain by, and cut off flush with, the top of the cliff by the main mass of the Northern and Cheviot Drift. [Length of section = about 440 yards.]*




MM. = Main Drift, very gravelly in places.

U.M.L. = Upper Magnesian Limestone.

B = Base of cliff and beach-sand.

S = Rock on the shore between tide-marks.

Fissure 3 contains only angular fragments of Magnesian Limestone and red and green marl.

Fissure 4, where exposed between tide-marks, yielded (at $x$) bones of *Elephas*, with tree-trunks and much shelly fresh-water clay, and at the sides crushed red marls.

Fissure 5, where exposed on the shore, yielded rodent teeth, peaty wood, shelly freshwater clay, and vegetable matter. Most of the seeds of pre-Cromerian age occurred in a small patch of brown clay at Y.

Fissure 4 is seen in the cliff, when the slipped clay has been washed away, to be about 70 feet wide. Between tide-marks it seems to have about the same width, and it continues out to sea, where it apparently narrows considerably. It contains large masses of peaty wood and tree-trunks, some of which I collected four years ago and sent to the late Clement Reid, F.R.S., who determined them as oak, alder, and pine.

The grey and black clay in which the tree-trunks are embedded is very rich in places in freshwater shells, the most conspicuous forms of which are species of *Anodonta*, *Limnæa*, *Planorbis*, *Valvata*, and *Pisidium*.

In this fissure, in some brown clay, apparently different from that containing the majority of the shells, on May 1st, 1918 (when nearly all the sand had been scoured away). I found some large mammalian bones which seemed to me to be elephant-remains. Pieces of an atlas vertebra occurred embedded in the clay, and a fragment of a rib was found, washed out among the shingle, but quite close to the other bone.

Fissure 5 is about 100 yards north of the last one, and contains between tide-marks a quantity of grey and brown clay with some fragments of trees not so big as those in Fissure 4, and much comminuted vegetable matter. The grey clay yields a large quantity of shells which do not seem to differ from those in the other fissure, except that perhaps the valves of *Pisidium* are more plentiful. Some rodent-remains were washed from a piece of brown clay in this fissure, and near it a mass of brownish rather sandy clay (apparently distinct from the blue clay that contains the majority of the shells) yielded on washing the bulk of the seeds that prove to be of such great interest.

The deposits in these two fissures are much mixed up, but traces of original stratification are clearly discernible, showing that some stratified deposits, together with part of the bed-rock on which they rested, were torn up, carried by the ice, and thrust, under great pressure, in a partly-frozen condition into the fissures and hollows. The whole may be regarded as a gigantic glacial erratic, and seems to have been bodily overturned, since most of the Permian marls, on which the freshwater clays rested, now occupy the higher part of the fissures.

The material is very strongly slickensided in places, but the smaller shells are generally complete, though the larger, such as *Anodonta* and *Limnæa*, may be crushed, indicating that the material was frozen during its transport. On the surfaces of the clay, when it has been washed clean by the sea, repeated faulting of the bedded material on a small scale can be well seen.

The seeds and other organisms are often pyritized, and veins of pyritized material are seen in the mass, apparently having originated subsequently to the thrusting of the material into the fissures.

The whole deposit is clearly very much broken up, and a separation of the different beds of clay on purely stratigraphical grounds seems impossible. However, after expert examination of

the included organic remains, it would appear that the brown rather sandy clay containing the majority of the seeds and the mammalian bones is older than the pale-blue and grey sticky clay in which most of the freshwater shells are found.

The former contains seeds of plants determined as belonging to a flora earlier than the Cromerian. The elephant-bones occurred in a rather similar clay, which did not apparently contain seeds, and are said not to belong to the mammoth, but without much doubt to *Elephas meridionalis*, a characteristic Cromerian species.

The evidence from the freshwater shells is less certain, and seems to indicate a later period; but Mr. A. S. Kennard & Mr. B. B. Woodward, who very kindly examined them for me, are inclined to modify this opinion, since so little is at present known of other freshwater shelly faunas of corresponding age in the North of England.

The grey and blue clay containing the numerous freshwater shells yields very few, if any, seeds; but a somewhat similar clay occurs in close association with it, which, though almost or quite devoid of shells, contains a quantity of small fish-bones and abundant Entomostraca. I washed a small quantity of seeds from a sample of this clay in Fissure 4. Mrs. E. M. Reid kindly examined these for me, and remarks that they differ from the material washed from the fragment of brown clay in Fissure 5, in the following details:—

(1) Unlike the other samples, the vegetable matter is not pyritized, or if so, in a very slight degree.
(2) It contains no moss, whereas the other samples do.
(3) Except three fruits, which apparently belong to some species of *Cirsium* or *Chamæpane* (thistle tribe), all the species are aquatic or riparian, and all, with the doubtful exception of the *Myriophyllum* and the *Cirsium* (?), are British species. There are ten species in all.
(4) It contains no restricted Teglian or Reuverian species.

Mrs. Reid goes on to say that it is highly probable that these differences indicate some difference of horizon, and that they certainly indicate a difference of habitat of the plants.

In all probability, the material, when in its original situation, formed a northerly continuation of the Pliocene and early Pleistocene (Teglian and Cromerian) freshwater deposits resting on a bed of Upper Permian marls some distance east of the coast, in what is now the bed of the North Sea; it was torn up bodily by the advancing foot of the Scandinavian ice-sheet, and thrust in a greatly commingled condition into the fissures and cavities of the rock.

## VI. Comparison and Correlation with the European Drifts.

I should feel inclined to regard the freshwater shelly clays with trees and seeds in the fissures on the Durham coast, on purely geological evidence, as the equivalent in age of the Cromer fluviatile

beds. The evidence from the contained organic remains lends, on the whole, support to this conclusion; but it also tends to show that the deposit is a mixed one, and that some pre-Cromerian beds were also caught up and carried along with it.

Many Continental geologists regard the Cromerian beds as belonging to the first Interglacial Period of Northern Europe; Dr. E. Haug refers them to the top of the Lower Quaternary.

The greatest extension of the Scandinavian ice-sheet seems to have taken place after the first Interglacial episode of Scandinavia; and it was in all probability the fringe of this ice-sheet that reached the Durham coast, and originated the peculiar deposits at present under description.

Mr. G. W. Lamplugh has stated his opinion[1] that the material on the Durham coast which I called 'Scandinavian Drift' is undoubtedly the equivalent of the Basement-Clay of Holderness. I am disposed, in general, to agree with this conclusion; but I may point out that I do not regard this correlation as absolutely certain, as I think that the Durham deposit may be earlier than the visible so-called 'Basement-Beds' in Holderness. The latter contain Scandinavian boulders mixed up with English and Scottish erratics; whereas in the Durham Scandinavian clay I have repeatedly searched, but without success, for English rocks other than the quite local Permian material. It is a 'pure culture' of Norwegian stones, no trace of Cheviot, Carboniferous Limestone, nor Whin Sill is to be found in it.

The Basement-Clay in South Yorkshire and in the Eastern counties south of Yorkshire seems, in its higher levels at any rate, to have been disturbed by the later local ice. Beds containing solely Scandinavian stones may occur in buried and unseen positions resting on the bed-rock in Holderness; but, so far as I am aware, or have myself seen, they are nowhere exposed at the surface.

The question whether the Scandinavian erratics in England were carried directly from their source of origin to their present site by an ice-sheet, or were rafted by melting icebergs into the North Sea and subsequently picked up by local glaciers which passed out into the North Sea and carried inland again, is one that still from time to time comes up for discussion in this country. It seems to be a relic of the old 'drift theory,' and should, if possible, be finally decided. At the same time, it must be admitted that the mingling of the Scandinavian, English, and Scottish rocks in the Basement shelly clays in Holderness appears to lend support to the iceberg-drift theory.

In my opinion, this theory has tended to obscure the true history of the early invasion of the east coast of England by the Scandinavian ice-sheet, and it is hoped that the evidence now brought forward will finally dispel the idea that the Scandinavian erratics in England were drifted hither by icebergs.

[1] Q. J. G. S. vol. lxxi (1915) p. 80.

I leave out of discussion the question of the deep area or fosse off the Norwegian coast, because it does not present any difficulty to my mind. It was probably filled with ice at an early stage, or, if not, it is now known that round the fringes of the Antarctic Continent the ice-cap floats in some places on deep water. One of the main points of evidence in support of the view of the gradual advance of the Scandinavian ice-sheet across the North-Sea area is the distribution of the different varieties of Scandinavian erratics along the east coast of England.

The Scandinavian Drift in Durham contains only Norwegian boulders, no Swedish erratics having been traced in it.

According to the work of Dr. V. Milthers on the Continent, in Holland the limit of the Drift that contains only Norwegian boulders lies south of the mouths of the Rhine and Maas, extending southwards and eastwards to Antwerp, and the island of Over Flakke. Milthers colours this area in a map[1] so as to indicate that only Norwegian erratics occur, and in the same map he provisionally indicates by the same colour that the whole of the east coast of England, from the Tees southwards to Norwich, including the eastern part of Yorkshire, Lincolnshire, and Norfolk, similarly contains only Norwegian erratics. This shows how small has been the amount of detailed glaciological work in this country compared with that accomplished on the Continent. Milthers is not correct in supposing these to be the limits in England of the Scandinavian erratics, for they have been traced over a much wider area in the south-eastern counties north of London than he indicates on his map. Neither is he correct in supposing that only Norwegian rocks occur in England, because it is well known that Swedish and Baltic rocks occur in Holderness, where I have picked up Swedish quartz-porphyries and Rapakivi Granites. I cannot, however, say that I have ever found the last-mentioned *in situ* in the undisturbed Basement-Clay, but I presume that such an occurrence has been recorded.

I do not know where in Yorkshire these Swedish rocks begin to occur, as I have never had the opportunity of examining the Yorkshire Drifts so closely as I have those farther north, but I presume that they begin to occur south of Flamborough Head. North of that point only Norwegian rocks will (I think) be found; but in Holderness, if an enumeration could be made of all the Scandinavian stones occurring *in situ* in the Drift, the Norwegian erratics would probably be found to number about 50 to 80 per cent. of the total Scandinavian erratics: the remainder being Swedish. This proportion, according to Milthers, characterizes the Drifts of Schleswig-Holstein and those about Hamburg.

These considerations, together with the occurrence of lœss and of the various materials carried in advance of the ice-sheet, tend to confirm the general agreement of the Scandinavian Drift of England with that of the rest of Northern Europe.

[1] 'Scandinavian Indicator-Boulders in the Quaternary Deposits' Danmarks Geol. Undersög. ser. 2, no. 23 (1909) pl. ii.

To my mind they show that icebergs in the North Sea had no action in distributing the boulders, and, in fact, the sea was entirely displaced by the great Scandinavian ice-sheet, which seems to have induced analogous steppe-like continental conditions of climate in England round its margin allowing the formation of similar lœss-deposits. The evidence pointing to an Interglacial episode for the accumulation and subsequent decalcification of this deposit is discussed later.

After the retreat of the Scandinavian ice-sheet from the Durham coast, we are concerned solely with the local English and Scottish Glacial deposits, which I am inclined to correlate with the third and latest Glacial deposits of Scandinavia and the North.

Climatic conditions, from one cause or another, had so altered in England that, at this period, the local glaciers occupied the coastal district in sufficient strength and thickness to hold off the Scandinavian ice from the coast, although they were themselves influenced and diverted to the south and south-west by its presence up to the latest period of glaciation.

The evidence of possible Interglacial intervals in the local Drifts is discussed later.

Since no true lœss has apparently been recorded in the British Isles in connexion with the local Glacial Drifts, it is to be assumed that the conditions prevailing during or after the occupation of the country by the local ice-sheets did not admit of the formation of that peculiar deposit. This is only what one might expect, in view of the fact that the climate is, and probably also was at that period, of an oceanic and not a continental character.

## VII. Evidence pointing to Interglacial Periods among the Durham Coastal Drifts.

When the Drifts are carefully examined, and the old hollows and Preglacial valleys carefully searched, the evidence in favour of at least one Interglacial episode becomes strengthened rather than weakened; although anyone taking a cursory glance at the Glacial deposits, and observing only the thick mass of the Northern Cheviot Main Drift of the Durham coast deposited during the latest stage of glaciation, might be inclined to assert that there had been only one Glacial episode.

The evidence that a pause of the nature and duration of an Interglacial period occurred between the retreat of the Scandinavian ice-sheet from the Durham coast and the oncoming of the local British glaciers seems to me to be very convincing.

The most important piece of evidence is, of course, that afforded by the bed of material which I have called 'lœss,' resembling so closely the Continental lœss in its physical and chemical properties as to put its identity practically beyond question. On the Continent this material is generally accepted as evidence of Interglacial and steppe-like conditions, and the calcareous concretions that occur

in it point to prolonged weathering and consequent decalcification of the incoherent substance.

In Europe the lœss is found almost exclusively along the southern border of the region that was occupied by the Scandinavian glacier at its maximum extension, and is sometimes Interglacial and sometimes Postglacial.

Further evidence, pointing to a pause of very considerable duration, is afforded by the decomposition and rotting of boulders and stones embedded in the lœss and lœss-like Drift near its upper surface. The most conspicuous example was that of a big rounded boulder of Norwegian titaniferous syenite, which I found embedded in yellow lœss-like Drift about a foot below its surface, on the top of the Magnesian-Limestone cliff, near the southern edge of the old Preglacial valley of Warren-House Gill.

The position of this boulder is indicated (*a*) in a diagram which I made of this section (fig. 2, p. 180). When I first saw it, at the end of 1913, some workmen had just thrown the boulder down from the cliff on to the sands below. It measured $3 \times 2{\cdot}5 \times 2$ feet, and had been resting directly on the calcreted rubbly surface of the rock, and much of the calcreted gravel was adhering to it. Its surface was rotted and decomposed to a depth of 3 inches or so, and pieces of the smooth boulder could be easily flaked off with a hammer. It has been lying on the shore exposed to the action of the waves for more than four years, and the rotted outer surface is now battered away, leaving the undecomposed inside portion. The rotting of its surface points to its having been exposed for a prolonged but indefinite period to the agency of weathering near the surface of the porous Drift, since it was carried across from Norway before the overlying local Boulder-Clays were laid down over it.

In a similar manner nearly all the smaller fragments of laurvikite and titaniferous syenite, together with many of the gneisses and schists buried near the surface of the Scandinavian Drift, are more or less completely rotted, often sufficiently so to crumble to pieces between the fingers.

I have noticed a similar decomposition in some of the granite- and gneiss-boulders in the higher parts of the latest kaim-like gravelly deposits in this district, but never so frequently as is the case in the upper layers of portions of the old Scandinavian Drift at Warren-House Gill.

In fact, the whole aspect, apart from the question of position, of the Scandinavian Drift and the various deposits connected with it and left in the hollows in the rock by the earliest invading ice-sheet, is a more ancient one. The clays and red and green marls are very strongly slickensided, a feature that I have never observed, or only to the very smallest degree, in the overlying local and later boulder-clays. The slickensiding points to direct transport beneath an ice-sheet of different character and of exceptional thickness.

The following points of general evidence of a less direct nature

can also be adduced, pointing to the possibility of a prolonged Interglacial interval after the retreat of the Scandinavian ice-sheet :—

(*a*) Evidence from the marine shelly faunas in the glacial beds.

(*b*) Possible Interglacial fluviatile erosion between the retreat of the Scandinavian ice and the oncoming of the local glaciation.

(*a*)—Various gravelly knolls and kaims left on the retreat of the latest Cheviot ice-sheet in the Durham coastal area, contain fairly abundant small waterworn fragments of marine shells, doubtless the scrapings of an old shore-line. They are especially abundant in a gravel-pit near the summit of one of the Sheraton kaims, $3\frac{1}{2}$ miles inland from the coast, at an altitude of 500 feet above sea-level.

On the assumption that there had only been one glaciation, it is difficult to understand how the latest movement of the ice travelling in a southward direction could include the material of a shore-line which presumably would have been already covered by ice or obliterated by the previous ice-sheets. I have for some time collected the shelly fragments from these kaim gravels, and find the series of mollusca to be of a decidedly less arctic character than those which occur in the much older Scandinavian Boulder-Clay at Warren-House Gill. An enumeration of the mollusca from these deposits is given on p. 194.

The Scandinavian Drift contains such thoroughly Arctic species as *Cardium islandicum* Linnæus, *C. grœnlandicum* Chemnitz, and the curious shell *Cyrtodaria siliqua* Spengler (now confined to Arctic America), forms apparently wanting in the later kaims. The latter contain, in fact, a fauna much more closely resembling that of the North Sea of the present day, with numerous individuals of *Tellina balthica* Linnæus and *Turritella*. Both deposits are unfortunately rather scanty in species, the kaims especially so, but the difference in the faunas, both evidently derived from the North Sea, is sufficiently striking.

It might, of course, be argued that the difference is due to difference of depth, and that the Scandinavian ice travelling across the North Sea tore up the mud containing the shells from fairly deep water, while the Cheviot ice skirting the shore-line contained a littoral fauna.

Mr. G. W. Lamplugh recently told me that he found that in Yorkshire the shells of the Middle Gravels are generally less Arctic than those in the Basement-Clay, but he considered that this implied that the Boulder-Clay shells had travelled some distance from the cold sea-bed, and that the gravels and their fossils were derived from the working-up of shore-deposits.

These facts agree with my observations of the Drifts of the Durham coast; but I am inclined to believe that the shells of the latest kaims represent the scrapings of an Interglacial and not of a Preglacial shore-line, with a fauna more closely approaching the present one.

The evidence for the Preglacial age of the Sewerby sub-Boulder-Clay beach near Bridlington is by no means conclusive, and the same remark applies to the 25-foot raised beach of the South-West of England and Wales.[1] The presence of *Corbicula fluminalis* in the Kelsey and Holderness deposits which are associated with the purple clay bearing Cheviot erratics also requires further explanation than many of the reasons that have been put forward for its presence there.

(*b*)—The valleys which have been eroded on the eastward-sloping surface of the Magnesian Limestone of the coastal area, especially those of Hesleden, Castle Eden, and Hawthorn Denes, have been described as Preglacial.[2] They are certainly Preglacial in the sense that they were eroded previously to the deposition of the main Cheviot and Scottish drift which now fills them.

I am, however, inclined to think that they may have been formed after the retreat of the Scandinavian ice-sheet from the coast, and that they are in reality Interglacial.

It is difficult to see how the Scandinavian ice-sheet filled up the small Preglacial valley of Warren-House Gill and yet failed to fill up the neighbouring but wider and deeper valley of Castle-Eden and Hesleden Denes if the latter were in existence previously to its oncoming. Certainly a Norwegian erratic was found some years ago in a deep excavation for the railway-viaduct near the entrance of Castle-Eden Dene, but it appears to have been a stray derived boulder similar to, but much smaller than, two now lying on the shore about $2\frac{1}{2}$ miles away to the south-east, which seem to have fallen from the Cheviot Drift that caps the cliffs.

No certain or direct evidence is, however, yet available on this point, as the drifts that occupy the bottom of the deeper of these gorges are buried out of sight; but there is a possibility that some of the valleys of the Magnesian-Limestone area of Durham were formed in the period intervening between the retreat of the Scandinavian ice and the oncoming of the local glaciation. They would therefore correspond in age with many of the Interglacial Chalk valleys of East Anglia described by Mr. F. W. Harmer.[3]

The Postglacial gorges of the coastal area are in some cases more or less definitely superimposed on the above-mentioned Pre- or Interglacial valleys, and are eroded through the Cheviot Drift, and some of them cut down into the underlying Magnesian Limestone for part of their course.

The present gorge of the Wear across and through the Magnesian-Limestone escarpment at Sunderland is a now familiar example. It has long been known that previously the Wear was a tributary of the Tyne, and that its old valley leading to that river is filled up with Glacial débris.

[1] A. L. Leach, 'On the Relation of the Glacial Drift to the Raised Beach near Porth Clais, St. Davids' Geol. Mag. dec. 5, vol. viii (1911) p. 465.

[2] D. Woolacott, Q. J. G. S. vol. lxi (1905) p. 64.

[3] 'The Glacial Deposits of Norfolk & Suffolk' Trans. Norfolk & Norwich Naturalists' Society, vol. ix (1910) p. 130.

In my previous paper on the Durham Drifts I described some water-deposited gravels, which occupy certain depressions in the Magnesian Limestone immediately underlying the Main Drift. One of the best examples of these occurs at a place known as Limekiln Gill, 4 miles north of Hartlepool, and another near Horden Point, $3\frac{1}{2}$ miles north-west of the last-mentioned occurrence. I gave an enumeration of the different stones that constitute the gravel at Limekiln Gill, where an unusually large proportion of gneisses and schists and of Scottish olivine-basalts occurs. At first, I was inclined to think that these gravels were deposited during a recession of the ice-sheet; but now, although the gravels underlie the main Cheviot Drift, I rather fancy that they were formed contemporaneously with the overlying Drift by subglacial streams, which probably at the same time eroded the small valleys wherein they are found. The general similarity of the material in the gravel to that forming the Main Drift, and the rather indefinite manner in which these gravels and sands merge into the overlying Drift, also induce one to take this view of their origin.

Prof. P. G. H. Boswell has recently described similar gravel-deposits in the Suffolk Drifts,[1] and has compared them with phenomena known in Schleswig-Holstein as Föhrden or Förden.

The evidence pointing to possible Interglacial episodes of any long duration among the local English and Scottish Drifts of Durham is, therefore, much less certain than that which relates to the pause following the retreat of the Scandinavian ice.

A mere superposition of one Drift upon the other, containing a series of erratics derived from another area, does not necessarily imply an Interglacial period; but it suggests that some interval of time may have occurred, to account for the shifting of the direction of flow and the readjustment of the ice-sheets.

There is a very definite case, in the Hartlepool area, of superposition of Drifts from different districts. An excavation to a depth of about 40 feet below sea-level in connexion with dock-excavations at Hartlepool showed the presence of a Drift certainly later than the Scandinavian Drift, but anterior to the Northern and Cheviot Drift which caps the sea-cliffs at Hartlepool.

This Boulder-Clay fills up an old Preglacial depression left by the solution of a mass of anhydrite and gypsum at Hartlepool, and contains erratics which, so far as I could see, were all of western origin, among them being those that had been carried across the Pennine Chain over the Stainmoor Gap. The opportunity that I had of examining this Drift some years ago led me to conclude that the Cheviot and other Northern erratics were absent from it. Unfortunately, it is nowhere exposed at the surface, and consequently the nature of its junction with the overlying Cheviot Drift cannot be seen; but it is possible that a pause of the nature of an Interglacial interval may have occurred between the deposition of this Drift and the oncoming of the ice that carried the Cheviot Drift, during which time the lobe of ice that crossed the Stainmoor Gap

[1] Q. J. G. S. vol. lxix (1913) p. 611.

had abandoned the coastal region and had been diverted down the Vale of York.

A fragment of earlier Boulder-Clay has thus been preserved in the Preglacial depression at Hartlepool. It is clear that a corresponding lobe was projected at about the same time through the Tyne Gap, and reached the coastal region. I know of no lower clays having been preserved in hollows (or by any other means) in the region of the mouth of the Tyne, such as might contain only western erratics corresponding with the lower clay at Hartlepool. South of a certain point in Northumberland, however, the Drift of the latest ice-stream that flowed southwards past the Cheviots is very rich in Lake-District rocks, which in the Durham coastal Drifts are often nearly or quite as plentiful as the Cheviot erratics.

It is clear that, unless there are previously existing hollows lying in the way ready to receive samples of the earlier Drifts, the material tends to become incorporated and merged in that derived from the next ice-sheet that flowed over it, especially if the ice-sheet passed over a rather elevated area, such as the Magnesian Limestone region of Eastern Durham.

## VIII. Sequence of Episodes in the Glacial History of East Durham.

The Glacial beds of the Durham coastal area prove to be of so varied and interesting a character that it is possible, tentatively and with the aid of evidence of the Glacial deposits of the adjacent counties, to construct a fairly-accurate mental picture of the sequence of events which caused their deposition.

I have also added a correlation with the Glacial events of the Continent, though it must be understood that this is of a suggestive rather than of an assertive nature.

| | |
|---|---|
| Submerged peat-bed at Hartlepool and Roker (near Sunderland), resting on the Cheviot Drift. | NEOLITHIC ? |
| Postglacial gorges cut.<br><br>Finely-laminated clays enclosing rafted erratics, distributed over a limited area around the mouths of the Tees and Tyne, probably deposited in lakes held up by a portion of the Cheviot ice-sheet still occupying the North Sea.<br><br>Dry watercourse at Ferryhill, eroded by water held up by ice, probably occupying the Tees valley and draining into the watershed of the Wear.<br><br>Drumlins and gravel-spreads in various parts of the area.<br><br>Gravelly moraine-heaps deposited on the retreat of the Cheviot ice and the ice coming through the Tyne Gap. The group that I called the Sheraton Kaims is aligned roughly north and south, and east and west. Those aligned north and south mark roughly the line of demarcation between the two ice-streams, and indicate the western limit of the region where material from the Cheviots is plentiful.<br><br>The gravels associated with the Cheviot Drift contain fragments of marine shells, flints, etc. torn up from a shoreline. | RETREAT PHASE. |

Diversion of the ice-sheet coming over the Stainmoor Gap down the Vale of York, and formation of the main Boulder-Clay of the Durham coast by the ice-sheet which swept past and partly across the Cheviots southwards and south-westwards towards the northern face of the Cleveland Hills. This sheet held up the lakes in the valleys of Cleveland. A lobe of ice at the same time crossed the Tyne Gap, and was diverted southwards west of and parallel to the Cheviot ice.

Possible Interglacial Interval (?).

The ice which crossed Stainmoor Gap passed directly eastwards out to sea down the Tees valley, and deposited the stony Boulder-Clays which fill an old depression (due to solution of anhydrite) at Hartlepool: these deposits have only been seen during dock excavations, and contain none but western erratics. This ice-stream carried the Shap granite-boulders, the northern limit of which in Durham is well defined.

At the same time a similar sheet crossed the Tyne Gap, and passed out to sea down the Tyne valley, carrying Lake-District rocks, which were later caught up by the Cheviot ice and incorporated in the Main Drift of the Durham coast.

} MAXIMUM OF THE LOCAL BRITISH GLACIATION.

Interglacial Episode.

Possible erosion of many of the valleys in Durham hitherto called Preglacial, which were filled in later by material carried by the local ice-sheets.

Probable formation of beaches on the east coast which yielded the shells and flints found in the Cheviot Drifts.

Weathering and rotting of Scandinavian boulders lying near the surface of the lœss and Scandinavian Drift at Warren-House Gill. Decalcification of the lœss.

Deposition of lœss overlying part of the Scandinavian Boulder-Clay at Warren-House Gill, and partial redeposition of the upper layers of the lœss by water.

} INTERGLACIAL.

Deposition of the main Scandinavian Drift which fills up the Preglacial depression of Warren-House Gill with slickensided grey and brown shelly clay containing Norwegian stones, fragments of Chalk, and local Permian material. Parts of this clay are mixed with lœss, showing that the advance was irregular and intermittent, also that lœss was deposited round the fringe of the ice-sheet as it advanced, and was overridden and caught up by it.

The fringe of the advancing Scandinavian ice-sheet tore up the red and grey marls and peaty freshwater deposits containing shells and plants which lay in its path, and thrust them into numerous hollows and fissures in the Magnesian Limestone which lay open in front of it. The transported material was strongly slickensided in the process.

} SECOND AND MAXIMUM ADVANCE OF THE SCANDINAVIAN ICE-SHEET.

Deposition of part of the freshwater shelly clays with seeds, trees, mammalian bones, etc. at some point east of the present coast-line, which were caught up later by the advancing ice-sheet.

} CROMERIAN OR FIRST INTERGLACIAL OF THE CONTINENT.

Deposition of freshwater clays with seeds of a pre-Cromerian flora east of the present coast-line, upon Permian red and green spotted marls.

} TEGLIAN.

## IX. Pleistocene Marine Mollusca from Durham.

The following is a revised list of the marine shells that I have collected in the Durham Drifts, including additional species found during the last four years. They are from two separate and distinct deposits, as follows:—

(*a*) The Scandinavian Boulder-Clay at Warren-House Gill.

(*b*) The Late Glacial kaims and gravel-heaps at Sheraton, and some smaller gravel-hills similar in origin to these kaims.

(Those marked with an asterisk are Arctic forms now extinct in British Seas.)

Scandinavian Drift.

**Pecten islandicus* Müller.
*Mytilus* sp.
*Leda* cf. *pernula* Müller.
*Cardium edule* Linnæus (rare).
**C. islandicum* Linnæus (common).
**C. grœnlandicum* Chemnitz (?).
*Cyprina islandica* Linnæus (common).
*Astarte sulcata* Da Costa.
*A. elliptica* Brown.
*A. compressa* Montagu.
**A. borealis* Chemnitz.
**A. arctica* J. E. Gray.
*Mya* cf. *truncata* Linnæus.
*M. arenaria* Linnæus.
*Panopæa norvegica* Spengler (?).
*Saxicava rugosa* Linnæus.
*Saxicava* large form (cf. *S. arctica* Linnæus).
**Tellina (Macoma) calcarea* Chemnitz.
*T. (Macoma) balthica* Linnæus (rare).
*Lucina borealis* Linnæus.
*Pectunculus* sp. (a fragment).
**Cyrtodaria siliqua* Spengler.
*Natica* cf. *grœnlandica* Beck.
*N.* cf. *clausa* Broderip & Sowerby.
*Buccinum*, a small form (cf. *B. grœnlandicum* Chemnitz).
**Neptunea* cf. *despecta* Linnæus (a fragment).
Valves of *Balanus* and tubes of *Serpula*.

Sheraton Kaims.

*Cyprina islandica* Linnæus.
*Tellina balthica* Linnæus (common).
*Saxicava* sp.
**Astarte* cf. *borealis* Chemnitz.
*A.* cf. *elliptica* Brown.
*Mactra* sp.
*Turritella communis* Risso.

Cyrtodaria siliqua Spengler. (Fig. 4, p. 195.)

This is one of the most interesting shells that occur in the Scandinavian shelly clay. It is fairly common, but always more or less fragmentary, though the pieces are easily recognizable if any part of the hinge remains.

The Durham fragments seem to have belonged to specimens of moderate size, measuring approximately (when restored) 52 mm. in length.

A species called *C. vagina* occurs in the Crag of East Anglia and Belgium, but there can be no doubt that the Durham fragments are referable to the recent species, *C. siliqua.*


Fig. 4.—Cyrtodaria siliqua *Spengler, from the Scandinavian Boulder-Clay of Warren-House Gill.* (*Natural size.*)

[The outline of the shell has been drawn in from comparison with recent examples. *a* = Portion of a right valve. *b* & *c* = Smaller portion of another right valve; exterior and interior views.]

It is recorded as *Glycimeris siliqua* from the Glacial beds of Caithness[1]: these are said to consist generally of a dull, dark leaden-grey or slate-coloured Boulder-Clay, which as a rule shows no trace of stratification, but contains fragments of Oolitic rocks

[1] J. Geikie, 'The Great Ice Age' 2nd ed. (1877) p. 589: list of the fossil organic remains, by R. Etheridge jun.

and Chalk, and throughout the deposit numerous broken shells, some of which show fine striations. Except for the presence of Oolitic rocks, the description applies very well to the Durham Scandinavian clay.

Its present distribution as a living species seems to be entirely American. Sir J. W. Dawson[1] records it as fossil at Rivière du Loup, Labrador (Packard), and Greenland (Möller), and says that from the first-named locality he only saw an imperfect and decorticated young shell. He records the recent shell from the Gulf of St. Lawrence and the coasts of Nova Scotia and New England. Further records[2] of the recent shell are as follows:—Maine: Casco Bay, at a depth of 5 fathoms; Massachusetts: Ipswich Bay; Nahant; off Princetown; Buzzard's Bay; Duxbury, etc., at 20 fathoms. I have a recent specimen labelled 'Newfoundland.'

It is recorded as having been dredged off Jan Mayen towards Greenland, at a depth of 1309 fathoms, having apparently been dropped from icebergs.

### Cardium islandicum Linnæus.

Next to *Cyprina islandica* this is the commonest species in the Durham Scandinavian Drift. Although it generally occurs in fragments, I have succeeded in recovering some perfect valves by collecting the pieces of crushed shells and joining them together again. They are of moderate size, the largest measuring about 40 mm. in length.

It is recorded from Dimlington and Bridlington, but not from the Cromer district.

Mr. A. Bell informs me that it is recorded with doubt from a Pleistocene deposit at Macclesfield (Cheshire), at 440 feet O.D. On the opposite side of the Atlantic the species occurs fossil at Rivière du Loup; Murray Bay; Portland (Maine), etc., and recent in Greenland and New England. Its range extends from the Arctic Ocean southwards to Cape Hatteras.[3]

### Cardium edule Linnæus.

For some years I thought that this species did not occur in the Scandinavian Drift at Warren-House Gill, but I recently found a few valves of it in a portion of the clay that had been uncovered by storms. It is much scarcer in this deposit than *C. islandicum.*

[1] 'Notes on the Post-Pliocene Geology of Canada' (Canadian Naturalist, vol. vi) 1872, p. 74.

[2] C. W. Johnson, 'Fauna of New England' Boston Soc. Nat. Hist. Occ. Papers, No. 13, vol. vii (1915) p. 78.

[3] W. H. Dall, Bull. U.S. Nat. Mus. No. 37 (1889) p. 52.

## X. Preliminary Description of the Plant-Remains. By Eleanor Mary Reid, F.L.S., F.G.S.[1]

The material sent to me has proved of the greatest interest. When washed and sifted from the matrix the total amount of vegetable matter was very small, not much more than a large tablespoonful, but it has yielded important results. I regret that I have not yet had an opportunity of working out the species in full detail, and of photographing the specimens. To do so would take more time than I can at present spare, but I hope to be able to complete the investigation in the near future.

Forty or more species have been found, exclusive of most of the *Cyperaceæ*, which number about twelve species. Of the total number rather more than half are exotic. Some may be extinct, but to decide this question further work is needed. Such plants as have been identified all point to a temperate climate, and therefore to a Pliocene age for the deposit. The large proportion of exotic species shows that the flora must be of an age earlier than the Cromerian. In the Cromerian about 10 per cent. of the flora was found to be exotic; in the Teglian about 50 per cent.; and in the Reuverian about 90 per cent. It is not easy to estimate the exact percentages, unless one has a complete collection of all British seeds; and this I do not possess. By comparing the percentages as given, it will be seen that the Castle-Eden flora corresponds very closely, in respect of the exotic element which it contains, with the Teglian; and it is to this age that I should assign the deposit.

Confirmation of this correlation is obtained along another line. The Teglian flora shows that at that time there still existed in this part of Europe a considerable element of the species having Chinese and North American affinities, which formed so conspicuous a part of the Reuverian flora. In how great a degree the Castle-Eden flora will show the same result I cannot at present say, as I have not yet had the opportunity of determining specifically many of the critical species. It is possible, however, to state that it does contain species which point strongly to the probability of this affinity. Thus, *Rubus flosculosus*, to which the Castle-Eden species seems closely allied, is a Chinese species; the gentian, which is not the European *Gentiana cruciata*, belongs to a section of the genus which, with but two or three exceptions, is entirely of Central and East Asian distribution; and most of the Cotoneasters with five stones (which all the Castle-Eden Cotoneasters possess), except *C. Pyracantha*, a plant of Central Europe and the Near East, and the section *Orientales*, also of the Near East, are either Central or Eastern Asian or North American.

[1] Mrs. E. M. Reid has very kindly sent me the appended results of her examination of the seeds and plant-remains, which she designates 'the Castle-Eden flora.' The great majority of these seeds were washed out of a mass of brownish rather sandy clay in Fissure 5, where it is exposed between high- and low-tide marks. The situation of the clay is indicated by Y on fig. 3, p. 182.—C. T. T.

The Castle-Eden flora also contains species known so far only from the Teglian and Reuverian, in some cases from the Reuverian alone. Unfortunately, some of these are Labiates the species of which we were unable to determine, when examining the material from those deposits, and the discovery of them at Castle Eden does not throw light on the present-day affinities of the deposit.

Such evidence of affinity, then, as is at present forthcoming tends to associate the Castle-Eden flora with the Teglian rather than with the Cromerian. In the Cromerian almost the last trace of the Chinese element had been exterminated by the ever-increasing cold; and, unless it be in the small *Urtica*, which occurs in the Cromerian, Teglian, and Reuverian, and was doubtfully assigned in the Reuverian memoir to *U. dioica*, there is no trace in the Cromerian of any of the peculiar Reuverian species.

Passing on to compare the assemblage of Castle-Eden plants with those from the other three Pliocene deposits, we find at once a great distinction. These, although differing in their component elements, yet show one marked characteristic in common: the great abundance, both in number of species and of individuals, of water-plants and waterside plants. In the Castle-Eden assemblage the case is quite different: instead of *Trapa*, *Najas*, pond-weeds, water-lilies, etc. occurring in the greatest profusion, at Castle Eden *Trapa* does not occur, there are a few nuts of pond-weed, one minute fragment of *Najas minor* (the only representative of a genus which in the other deposits occurs abundantly), and no water-lilies at all. Instead of these, we have as the commonest species *Potentilla argentea*, essentially a plant of dry banks and gravelly places.

This distinction in the floras seems to point to a difference of habitat, not of climate; or more correctly, only to such difference of climate as would correspond with a difference of habitat.

In the case of the Reuverian, Teglian, and Cromerian deposits there can be little doubt that they contain the débris of great rivers, on the banks and in the quiet backwaters of which grew an abundance of water-plants, and the courses of which lay through a varied country, largely forest-land. The Castle-Eden deposit points to other conditions: here the absence of plants inhabiting slow mud-bottomed streams, or pools, shows that the stream which deposited the débris probably ran clear over a rocky or pebbly bed. The presence of rock-loving and bank-loving plants, such as *Cotoneaster*, *Potentilla argentea*, and *Oxalis corniculata*, confirms this interpretation. Probably the stream was an upland one flowing through a rocky valley with pastures, having somewhat the character of an Alpine valley.

It follows that, in comparing the climates of Castle Eden and Tegelen as shown by their fossil floras, we are comparing the climate of an upland valley in the North of England with that of the lowlands of Limburg. These would not, contemporaneously, have the same character in the past any more than they have to-day. That consideration necessitates a slight correction as to

age, which would set the Castle-Eden deposit farther back in time than the Teglian, a time when the destruction of exotics in the uplands of Castle Eden had attained a proportion which later it was to attain in the lowlands of Limburg. The amount of correction involved is very small, and scarcely affects the argument that

| Species. | Cromerian. | Teglian. | Reuverian. | Exotic or extinct. | Remarks. |
|---|---|---|---|---|---|
| *Sparganium ramosum* Hudson? | + | ? | | | A single fruit, badly pyritized. |
| *Potamogeton acutifolius* Link | | + | | | |
| *P. pectinatus* Linnæus | + | + | | | |
| *P.* sp. | — | — | — | + | |
| *Najas minor* Allioni | + | + | | + | A fragment of a single seed. |
| *Cyperus* sp. | — | + | — | + | =Tegelen sp. 1 (1910, fig. 49). |
| *Cladium mariscus* Robert Brown? | — | — | ? | ? | Very small. A small form of Reuverian age was found at Bidart. |
| Cyperaceæ | | | | | About twelve species. |
| *Carpinus betulus* Linnæus | + | + | + | — | A very small form. |
| *Betula alba* Linnæus | + | — | — | — | |
| *Alnus viridis* Chaix | — | + | — | + | |
| *A. glutinosa* Gærtner | + | — | | | The seeds are rather small. |
| *Urtica dioica* Linnæus? | + | + | + | ? | The sp. occurs in C., T., & R., but doubtful whether living British. |
| *Chenopodium* sp. | — | — | — | + | |
| *Ranunculus* cf. *humilis* Huet de Pavillon | — | + | — | + | |
| *R. sceleratus* Linnæus? | + | + | | | A single achene badly preserved. |
| *R. lateriflorus* DeCandolle | — | — | + | + | |
| *R.* sp. | — | — | — | + | |
| *Liquidambar?* | — | — | ? | + | A fragment may belong to this genus. |
| *Cotoneaster acuticarpa* Reid | — | — | + | + | |
| *C.* sp. 2 | — | — | — | + | |
| *C.* sp. 3 | — | — | — | + | |
| *Rubus flosculosus* Focke? | — | — | ? | + | A Chinese sp. The Reuverian sp. 2, pl. ix, figs. 14–16, probably belongs to the same sp. |
| *Potentilla argentea* Linnæus | — | + | — | | |
| *P.* sp. | — | — | ? | + | ? The same as a species found at Bidart. |
| *Ilex* cf. *aquifolium* Linnæus | — | — | — | + | |
| *Viola palustris* Linnæus | + | | — | | |
| *V.* sp. | | | | | |
| *V.*? | | | | | |
| *Hippurus vulgaris* Linnæus | + | | | | |
| *Gentiana*, sect. *Aptera* | — | — | — | + | Allied to *G. cruciata*. The section is chiefly Central and East Asian. |
| Gentianaceæ? | — | + | — | + | |
| *Ajuga reptans* Linnæus | + | | | | |
| Labiatæ sp. 1 | — | — | + | + | Reuverian flora. Pl. xvi, fig. 24. |
| Labiatæ sp. 2 | — | + | + | + | Tegelen, 1910, fig. 42. Reuverian, pl. xvi, figs. 25–27. |
| Labiatæ sp. | | | | | |
| Compositæ? | — | — | — | + | |

About six other species are found. The position of these has so far not been determined: it is probable that they are mostly exotic.

NOTE.—Circumstances arising from the War having left the Teglian and Reuverian type-specimens in my temporary care, I have been able to compare the Castle-Eden specimens with them in every case where it was needful.

the Castle-Eden deposit is approximately of Teglian age. It may be a little older, but is not newer.

I append a list of species (p. 199) showing, so far as I have been able to determine it, the relation of the Castle-Eden plants to living British, and to Cromerian, Teglian, and Reuverian plants.

## XI. Description of the Mosses. By Hugh Neville Dixon, M.A., F.L.S.

I have identified the following:—

| | |
|---|---|
| *Neckera complanata* (L.) Huebn. | *Thuidium (?tamariscenium)* (L.) B. & S. |
| *Homalia trichomanoides* (Schreber) B. & S. | *Eurhynchium swartzii* (Turn.) Hobk. |
| | *Eurhynchium prælongum* (L.) Hobk. |

Also a fragment which may be something different, but possibly also *Eurhynchium swartzii.*

The first two are arboreal mosses, the others terrestrial. They are all the ordinary species that one might meet in a wood, or a lane-side now, in any lowland part of England.

## XII. Description of the Non-Marine Mollusca. By Alfred Santer Kennard, F.G.S., and Bernard Barham Woodward, F.L.S., F.G.S.

Nineteen species of mollusca were sent to us by Dr. Trechmann, which he had obtained by washing the clay. The species were:—

| | | | |
|---|---|---|---|
| *Succinea putris* (Linnæus). | Rare. | *Valvata piscinalis* (Müller). | Common. |
| *S. pfeifferi* Rossmässler ? | Do. | *V. cristata* Müller. | Rare. |
| *Limnæa pereger* (Müller). | Common. | *Unio* sp. | Do. |
| *L. palustris* (Müller). | Rare. | *Anodonta cygnæa* (Linnæus). | Do. |
| *L. truncatula* (Müller). | Do. | *Pisidium amnicum* (Müller). | Do. |
| *L. stagnalis* (Linnæus). | Do. | *P. casertanum* (Poli). | Common. |
| *Planorbis lævis* Alder. | Common. | *P.* cf. *lacustris* B. B. Woodward. | Do. |
| *P. crista* (Linnæus). | Do. | *P. nitidum* Jenyns. | Do. |
| *P. umbilicatus* (Müller). | Rare. | *P. subtruncatum* Malm. | Do. |
| *P. leucostoma* Millet. | Do. | *P. henslowanum* (Sheppard). | Do. |

Since there is an almost total absence of characteristic species, it is difficult to speak definitely as to the age of the bed. They are all living forms, but the abundance of *Planorbis lævis* shows that we are dealing with a deposit of some antiquity. If we judge from the known facts, the bed may well be the equivalent of the Crayford Brickearths or rather later.

*Valvata piscinalis* is not known to occur at an earlier horizon, and, although the examples are not typical, they must be referred to that species.

It should, however, be remembered that we have practically no knowledge of the pre-Holocene Mollusca of the North of England, and therefore it is quite possible that the deposit may be older than our present knowledge warrants us in inferring.

## XIII. Description of the Bones of *Elephas*. By Charles William Andrews, D.Sc., F.R.S., F.G.S.

I have examined the bones sent to me by Dr. Trechmann, and find that they are parts of a rib and an atlas vertebra of an Elephant. Comparison shows that the atlas is not that of *Elephas primigenius*, but that it approaches very nearly to specimens of the atlas of *E. meridionalis*, with which I have been able to compare it. The material is not good enough for absolute certainty in determination, but I do not think that there is much doubt.

## XIV. Description of the Rodent Teeth. By Martin A. C. Hinton.

These specimens are an incisor and an anterior cheek-tooth (*m.* 1 of ordinary numeration), both of the left upper jaw; they probably come from one animal, and are accompanied by some minute fragments of the premaxillæ and maxillæ. The cheek-tooth is obviously young, since its worn surface shows thin enamel and confluent dentinal spaces; an examination of the pulp-cavities shows that the dentinal spaces would be closed by the re-entrant enamel folds in more adult stages of wear. In size both teeth agree perfectly with those of the species of *Mimomys* which occur in the Upper Freshwater Bed of West Runton (Norfolk). Further, the crown pattern of the cheek-tooth shows certain minute features, of an ephemeral kind, similar to those that I have observed in correspondingly young teeth of *Mimomys*. The tooth shows no sign of rooting, and rooted molars are, of course, the most striking characteristic of *Mimomys*—when adult; but similarly young teeth of *Mimomys* from West Runton are wholly without signs of rooting also.

The Durham material is insufficient for me to say positively that it should be referred to *Mimomys*; but had I found it at West Runton or in the High-Terrace Drift of the Thames I should have had no hesitation in determining it as the remains of a young individual of that genus. It is to be hoped that further search will be made in County Durham; for these specimens lead me to believe that somebody has a very good chance of making an important discovery there.

### Discussion.

Dr. C. W. Andrews remarked that he had carefully examined the fragments of the atlas vertebra of an elephant and that, although the specimen was very imperfect, it was possible to be almost certain that it did not belong to *Elephas primigenius*, and that it was much more like the atlas of *E. meridionalis* than that of *E. antiquus*. The cervine astragali mentioned by the

Author appeared to be of more recent date than the proboscidean remains.

Mr. A. S. Kennard wished to congratulate the Author on a most important piece of work, and one that added much to our knowledge. Hitherto the Pleistocene fauna and flora of Durham were unknown, and the careful methods of collecting adopted had filled up a gap in our knowledge. It was clear, from the varying composition of the matrix, that deposits of more than one age were present in the fissures, and this would account for the several horizons indicated by the contained fossils.

Dr. Stanley Smith remarked upon the brecciated appearance of the clay, as an indication of the frozen state of the material at the time when it was rammed into the fissures.

Mr. C. E. N. Bromehead particularly welcomed the Author's attempt to correlate the sequence of Drift deposits with the Glacial epochs recognized on the Continent. Apparently the Author referred the Scandinavian Drift to the Riss, and the local Drift to the Würm stages. That agreed well with the conclusion arrived at by Mr. Dewey and himself in the Thames Valley, that the Chalky Boulder-Clay and the late Pleistocene Arctic period of Ponder's End, etc. corresponded with the same stages. The later fossiliferous deposit found by the Author beneath the local Drift contained freshwater mollusca, which Mr. Kennard said were not older than late Pleistocene; it might be roughly contemporaneous with the Ponder's-End deposits. Again, the Author regarded the period between the two stages as one of rapid denudation, and referred the formation of Castle-Eden and Hesleden Denes to it; that agreed well with a large amount of erosion in the Thames Valley between the Chalky Boulder-Clay and the Arctic period. All such correlations were necessarily hypothetical, but the more they were attempted for different districts, the greater was the chance of arriving at a definite conclusion.

The President (Mr. G. W. Lamplugh) said that the Author was to be congratulated upon a notable addition to our scanty list of fossiliferous Preglacial or early-Glacial deposits in Britain. That the fossils were found between tide-marks is in keeping with the usual condition on the East Coast, as in this position, where the deposits are permanently saturated, the fossils are more likely to be preserved than at higher levels where they are subjected to the circulation of ground-water. The deposit described as lœss seemed hardly to deserve the prominence ascribed to it by the Author. The heterogeneous Drift-material of the Yorkshire coast included many limited local deposits of peculiar composition, doubtless due to the complex conditions at or near the fluctuating ice-border, and these were particularly numerous and variable in Holderness between the Basement-Clay, which was the equivalent of the Author's 'Scandinavian Drift,' and the Purple Clay, equivalent to part of his 'Main Drift.' But, in many places, there was evidence for uninterrupted glacial conditions, from the deposition of the lower Boulder-Clay to that of the higher. The significant feature of

lœss in the typical regions was its wide extension in homogeneous sheets; and it seemed hardly advisable to apply the term specifically to a small isolated patch, such as that described. The Author's attempt at a general classification of the Drifts on the basis of the Durham sections deserved consideration, but was necessarily of limited value, like the many previous attempts of this kind. The speaker's experience had been that the sharp boundaries observable among the East-Coast Drifts in several localities, though often traceable for some distance, always faded out sooner or later, and were not confined to any particular horizon.

## 11. *The* PLEISTOCENE DEPOSITS *around* CAMBRIDGE. By JOHN EDWARD MARR, Sc.D., F.R.S., V.P.G.S., Woodwardian Professor of Geology in the University of Cambridge. (Read November 19th, 1919.)

[PLATE XI—SECTIONS.]

### I. INTRODUCTION.

SINCE the year 1910 I have devoted considerable attention to the Pleistocene Deposits of the Cambridge district, and believe that my observations will be useful as an aid to future students of these accumulations.

In a paper read before the Cambridge Philosophical Society in 1917,[1] I gave a brief account of the conclusions which I had reached, and noted the importance of a study of the Pleistocene deposits of the Great Ouse Basin,

'for in this area we get evidence of the relationship of the Palæolithic deposits to those which were formed during a period of submergence and re-emergence, and also to accumulations which give evidence of the occurrence of more than one cold period.'

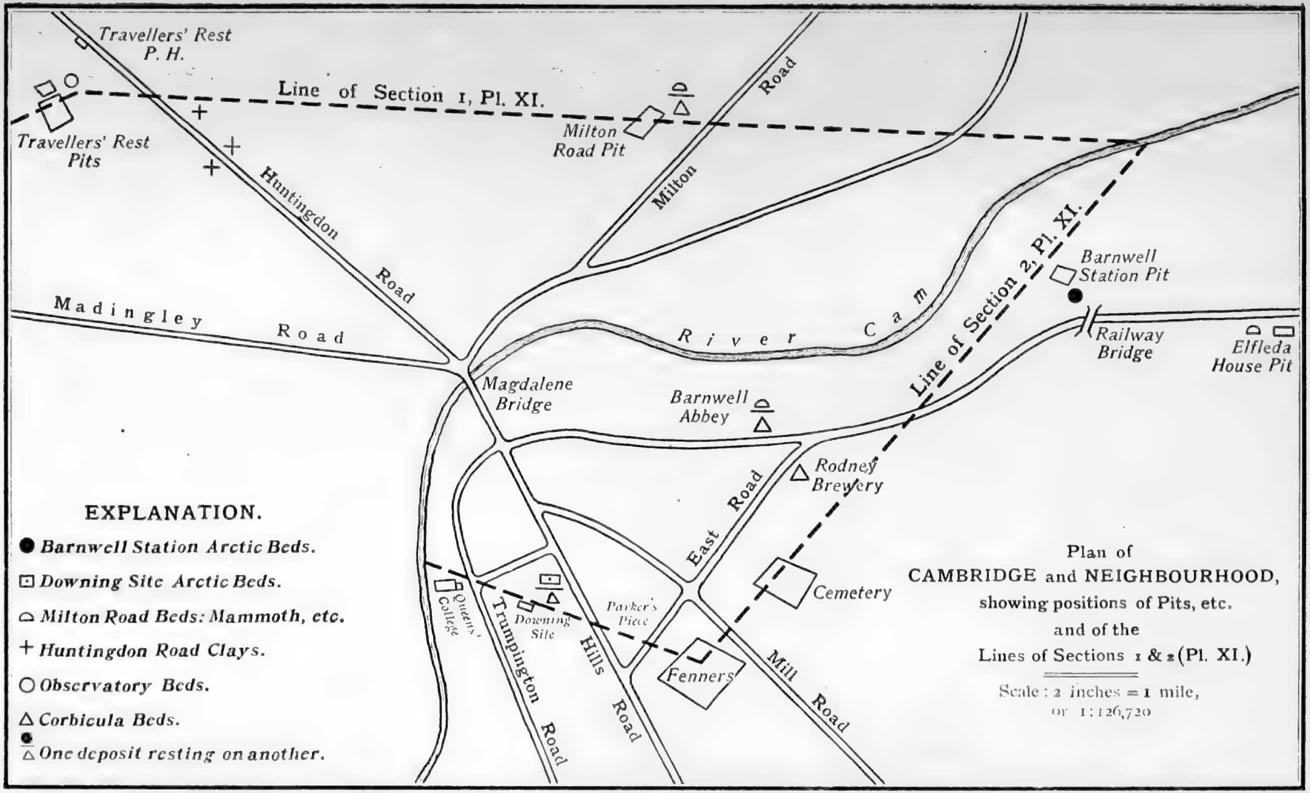
In the present paper I propose to confine myself to a consideration of the deposits in the immediate neighbourhood of Cambridge, with special reference to the sequence of the various members of the Pleistocene accumulations as there displayed (see fig. 1, p. 205).

In the previous literature devoted to this subject undue stress has been laid upon relative elevation above present river-level. Of recent years it has been recognized that, owing to alternate erosion and aggradation, difference of level must be treated cautiously, for reasons which I gave in the paper to which I have referred. The researches of palæontologists have enabled us to construct a time-scale based upon fossil evidence (including that furnished by human implements), and I have relied largely upon this evidence in attempting to determine the time-sequence of our local deposits. In doing this, the collections made in past years have been of considerable value; but, as many of the localities from which specimens were obtained are only vaguely given, with the result that specimens from different horizons are recorded as coeval, I have, with the aid of many students and others, done a large amount of careful collecting, in order to find out exactly what fossils are associated together. The result is that I am led to modify to a considerable extent the classification of the deposits as made by earlier writers.

The most important work previously done in connexion with the deposits under consideration will be found recorded in the Geological Survey Memoir, 'The Geology of the Neighbourhood of

[1] Proc. Camb. Phil. Soc. vol. xix (1917) p. 64.

Fig. 1.



Travellers' Rest P. H.
Line of Section 1, Pl. XI.
Travellers' Rest Pits
Huntingdon Road
Milton Road Pit
Milton Road
Madingley Road
River Cam
Line of Section 2, Pl. XI.
Barnwell Station Pit
Railway Bridge
Elfleda House Pit
Magdalene Bridge
Barnwell Abbey
Rodney Brewery
East Road
Cemetery
Queens' College
Trumpington Road
Downing Site
Hills Road
Parker's Piece
Fenners
Mill Road
EXPLANATION.
Barnwell Station Arctic Beds.
Downing Site Arctic Beds.
Milton Road Beds: Mammoth, etc.
Huntingdon Road Clays.
Observatory Beds.
Corbicula Beds.
One deposit resting on another.
Plan of CAMBRIDGE and NEIGHBOURHOOD, showing positions of Pits, etc. and of the Lines of Sections 1 & 2 (Pl. XI.)
Scale: 2 inches = 1 mile, or 1:126,720

Cambridge' by W. H. Penning & A. J. Jukes-Browne, published in 1881; and in that memoir will be found references to previous literature.

Since the publication of that memoir many details have been added, especially by the late Prof. T. McKenny Hughes, in a paper on 'The Gravels of East Anglia.'[1]

It is a great pleasure to record the help that I have received from many students past and present, and others, including American, Australian, and Canadian officers who studied in Cambridge during the summer of 1919. The list is so long that I cannot cite the names, though some will be mentioned in the course of the paper. The enthusiasm displayed by these helpers encourages me to hope that in future years a detailed survey of the Pleistocene deposits of the Great Ouse Basin will be undertaken by the students of the Cambridge School of Geology, and I believe that this preliminary paper will be of assistance to them in carrying out further work, though I trust that it will also be useful to workers in other districts.

I desire also to record my indebtedness to the late Mr. Clement Reid, F.R.S., and to Mrs. Eleanor Reid, for determination of plant-remains; to Mr. A. S. Kennard & Mr. B. B. Woodward, for identifying mollusca; to Mr. M. Burkitt, for help with the implements; and to Mr. C. E. Gray, for identification of mammalian bones. Mr. Kennard & Mr. Woodward and Mr. Burkitt have been so good as to furnish Appendices to the paper.

I would acknowledge the courtesy and help extended by pit-owners and workmen on all occasions. The thanks of Cambridge geologists are specially due to Messrs. Swann for allowing free access to their pits.

## II. The Time-Sequence.

The Geological Surveyors classified the Pleistocene deposits of the Cam Valley as follows:—

| | |
|---|---|
| Gravels of the Present River-System. | Lowest Terrace.<br>Intermediate Terrace.<br>Highest Terrace. |
| Gravels of the Ancient River-System. | |

I shall give reasons for supposing that the gravels referred to the ancient river-system are in part contemporaneous with those assigned to the present river-system, and that the latter contain deposits of very different ages, some having been formed during a period of aggradation, others during one of erosion. In the absence of continuous sections it is usually difficult to ascertain whether the gravel of a higher 'terrace' reposes upon one at a lower level, or whether the deposits of the latter are banked against those of the former. In the former case, the more elevated gravels are the newer; in the latter, those at a less elevation.

In the paper published in the Proceedings of the Cambridge

[1] Cambridge University Press, 1916.

Philosophical Society I arranged the deposits, so far as I had then studied them, in the following order :—

Barnwell-Station Beds.
Upper Barnwell-Village Beds.
Observatory Beds.
Lower Barnwell-Village Beds.

Since then other deposits have been studied, but those enumerated in that paper seem to be the most important.

It will be convenient to describe the deposits in the order of what I believe to be their relative ages, beginning with the oldest. The general distribution of the deposits will be made clear by the accompanying sections, one of which is from Elfleda House, a mile east of Barnwell, across the Observatory Ridge to the Madingley Road (Pl. XI, fig. 1), and the other from Barnwell Station to Newnham (Pl. XI, fig. 2).

## (*a*) The *Corbicula* Beds = Lower Barnwell-Village Beds.

The occurrence of *Corbicula* in various places around Cambridge has been recorded in previous writings, in deposits which the Geological Surveyors refer to the Highest Cam Terrace of the gravels of the present river-system, though I hope to show that deposits of different ages belong to this 'terrace.' In the immediate vicinity of Cambridge the *Corbicula*-bearing beds are found at a height of 20 to 45 feet above sea-level. They are usually covered by gravels and sands which appear to be of later date, though at the Rodney Brewery, Barnwell, they apparently occur immediately below the surface-soil, as shown in the section given by the late Prof. Hughes, in his paper on the gravels of East Anglia, fig. 31, p. 45. In addition to this place, *Corbicula* has been found near Barnwell Abbey, the old locality, long since covered; at the Milton-Road gravel-pits, immediately north of the junction of that road with the Chesterton Road; and in a section to be presently described, in the Museum grounds on the Downing Site. It is interesting to note that the beds on this site are referred by the Surveyors to the 'Intermediate Terrace' and not to the 'Highest Terrace.' The deposits consist of gravel, sands, and loams, the molluscs being usually found in a pale buff-coloured sandy loam. From the Barnwell-Abbey and Milton-Road Pits a rich mammalian fauna is recorded; but the fossils were chiefly derived from the beds in the upper parts of the pits, whereas the *Corbiculæ* came from beds at the base which were not often exposed. As the deposits lie at about the same level over a wide area, they were probably formed on an extensive alluvial tract, and some may even be lacustrine.

In trying to determine the age of these beds, one must discuss the palæontological evidence; for there seems to be a conflict of opinion in this country as to the age of the Pleistocene *Corbiculæ*.

A very significant feature is the frequent association here of

*Corbicula* and *Hippopotamus*, and it is one which requires consideration. In this connexion reference must be made to the Barrington Beds, which have yielded so rich a mammalian fauna, including abundant remains of *Hippopotamus*. The occurrence of *Corbicula* in these beds has been disputed; but Mr. C. E. Gray, Chief Assistant at the Sedgwick Museum, in 1901 collected mollusca from the basal deposits at Barrington: these were identified by Mr. Hugh Watson in 1918. The list is as follows:—

*Arianta arbustorum* Linné.
*Corbicula fluminalis* Müller ?
*Bithynia tentaculata* Linné.
*Limnæa pereger* Müller.
*Pisidium amnicum* Müller.
*Helicella itala* Linné.
*Succinea putris* Linné.
*Cochlicopa lubrica* Müller.
*Valvata piscinalis* Linné.

There is a query after the *Corbicula*, but, if not the true *fluminalis*, it is a closely-related variety.

We may now consider the occurrence of *Hippopotamus* in the immediate vicinity of Cambridge. It has been recorded in four places, namely, the Old Botanic Gardens Site north of Downing Street, the present Botanic Gardens, Barnwell, and Chesterton. The specimen from the Old Botanic Gardens has been in the Sedgwick Museum for a long time. The late Prof. Hughes, in a note attached to the specimen, observed the similarity between the matrix and that of the *Hippopotamus*-bearing beds at Barrington, and suggested a mistake in the naming of the locality. The discovery of a similar matrix in beds with *Corbicula* in the Downing Site grounds, and the recent extraction of the astragalus of *Hippopotamus* from the present Botanic Gardens, make it most probable that there was no mistake. It must be noted, moreover, that the Old Botanic Gardens specimen was found at a time long before the discovery of the Barrington deposits. Hughes also throws doubts on the Barnwell specimens. He states, in his paper on the gravels of East Anglia, 1916, p. 52:

> 'In our collection . . ., although there are a few specimens of *Hippopotamus* labelled from Barnwell, there is something suspicious about them. The bones are not in the same condition as those of the other animals found with them and respecting which we have no doubt.'

This, however, would be accounted for if, as I believe, the other bones came from a newer horizon in the upper parts of the pits. It is noteworthy that, in addition to *Corbicula*, *Unio littoralis* and *Belgrandia marginata* have been recorded from these Barnwell gravels; and the occurrence of these shells with *Hippopotamus* suggests an earlier date for these deposits than that of the associated deposits with the mammoth, woolly rhinoceros, and their accompaniments. Dr. F. R. C. Reed, in his 'Geology of Cambridgeshire' 1897, p. 209, records *Hippopotamus* from Milton Road, Chesterton. He believes that the information was supplied to him by Prof. Hughes, but unfortunately no specimen from this site can be found in the Museum.

The following mollusca were determined by Mr. A. S. Kennard,

from the Lower Molluscan Bed on the Downing Site, of which the section will be described later:—

| | |
|---|---|
| *Valvata piscinalis* Müller. | *Sphærium corneum* Linné. |
| *Hygromia hispida* Linné. | *Pisidium amnicum* Müller. |
| *Corbicula fluminalis* Müller. | *Pisidium henslowianum* Sheppard. |

I may here note that the basal gravel of these *Corbicula*-bearing beds of the Downing Site contained many boulders, chiefly of flint; but one large mass of Gault (shown in the section, p. 225) was found, and many of Chalk-Marl. Jurassic boulders also occurred, and one igneous rock. A boulder of quartzose rock $9 \times 6 \times 4$ inches had phosphate-nodules attached to it, and has been washed into the gravel from the Cambridge Greensand.

In the old collections from the pits near Barnwell Abbey are some plants which may have come from these beds, but unfortunately they tell us nothing. They were examined some years ago by the late Mr. Clement Reid, who says that all the leaves that are determinable seem to belong to one species of *Salix*, apparently *S. repens*.

A few words concerning worked flints which may have come from these beds may be added.

Certain artefacts have been obtained from the deposits of the 'Highest Terrace' which I believe to be of Upper Palæolithic date and to have been derived from deposits newer than the *Corbicula*-Beds. These will be noticed later.

Those to which I would refer as possibly out of the *Corbicula*-Beds are of Lower Palæolithic type, and probably all Chellean.

A large coup-de-poing from Barnwell, described by Mr. A. F. Griffith,[1] was presented by him to the Sedgwick Museum.

An implement obtained by the Rev. O. Fisher from Chesterton is mentioned by Sir John Evans.[2] This is also in the Sedgwick Museum. It is a small worn oval implement with orange surface. The position in Chesterton in which it was found is not recorded.

In the same Museum are two other implements of the coup-de-poing type. One is labelled as from a heap of gravel in Mill Road, brought from Chesterton in 1879. The other was obtained by a workman in the Milton-Road Gravel-Pit in 1912, and stated to have been found 6 feet below the surface. Both of these are much waterworn.

Two implements of the coup-de-poing type, labelled Chesterton, are preserved in the Museum of Ethnology, but nothing seems to be known about the circumstances of their discovery.

A well-trimmed brown flake 5 inches long was purchased from a Cambridge dealer by Mr. J. Reid Moir, who presented it to the Sedgwick Museum. It was stated by the dealer to have been found on the site of the Catholic Church in Hills Road, a spot which is

[1] Geol. Mag. dec. 2, vol. v (1878) p. 400.

[2] 'Ancient Stone Implements of Great Britain' 2nd ed. (1897) p. 538.

on the 35–40-foot plateau on which the old and new Botanic Gardens Site and the Downing Site are located.

A gravel-pit on the Royston Road, half-a-mile south of Trumpington, close to the London & North-Western Railway, is outside the limit of the tract which I am describing in detail; but, as Mr. Kennard treats of the shells found there, I may notice the occurrence of worked flints in this deposit, one of which, found by the late Mr. St.-H. Lingwood, is apparently of Chellean type. The shells were collected by Miss M. E. J. Chandler, Mr. T. C. Nicholas, and myself.

It is important to note that the localities in which these implements were found are at elevations considerably below that of the Observatory Gravels to be described later, as are also the Barrington Beds.

Taking all the fossil evidence into consideration, it would appear that in Chellean (or possibly pre-Chellean) times a valley existed in the vicinity of Cambridge, the bottom of which was there not more than 20 feet above present sea-level, and only about 10 feet above the present river. The evidence on the ground agrees with the palæontological evidence in pointing to the correlation of these deposits with the *Corbicula*-bearing beds containing marine fossils at Bluntisham and March, although A. J. Jukes-Browne correlated the latter with the gravels of the Ancient River System (Observatory Gravels, etc.).

There is, then, evidence in the neighbourhood of Cambridge of deposits at 25 to 40 feet above sea-level containing *Corbicula fluminalis*, *Unio littoralis*, *Belgrandia marginata*, *Hippopotamus*, and implements of Chellean type. These deposits we may, after consideration of the recent discoveries in North-Western France, confidently refer to an early age of Palæolithic times, and some may even be anterior to those times.

### (*b*) The Observatory Gravels.

These deposits now occupy a ridge separating the Cam Valley on the east from a minor valley on the west which is drained by two streamlets, one flowing northward into the Great Ouse and the other southward into the Cam. The gravels reach a height of 84 feet at the Observatory and of about 88 feet near the Traveller's Rest, some half-a-mile north of this.

The deposits appear to have been laid down originally in the small western valley, and not in that now occupied by the Cam: for the base of the gravel is about 20 feet lower near the Madingley Road than it is where it ends on the eastern side of the present ridge, as shown in the section (Pl. XI, fig. 1). This is recorded by the Geological Surveyors,[1] who further note that a section exposed in 1873 showed

> 'that the gravel of Gravel Hill, on which the Cambridge Observatory is built, lies banked up against the S.W. side of the Chalk Marl ridge.'

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[1] 'The Geology of the Neighbourhood of Cambridge' Mem. Geol. Surv. 1881, p. 89.

Two pits belonging to Messrs. Swann have been worked during the last few years close to the Traveller's Rest Inn. These I shall speak of as the North and South Pits: the former is now closed. I have studied the sections continuously since 1911, and obtained a considerable number of implements from them, which will be noticed presently.

Some measurements will give an idea of the extent of the sections. The North and South Pits lie side by side, with an interval of a few yards between them. Continuous sections were exposed in the south-western faces of the two pits, and are still seen in the southern pit. The continuous section of this pit is about 130 yards long, that of the northern pit having been about 30 yards. The total length of the southern pit at right angles to this face is approximately 100 yards.

A very fine section is now (1919) exposed on the south-western face of the South Pit, of which the following is a generalized sketch, details of which are copied from photographs kindly taken for me by Mr. R. H. Rastall (fig. 2, p. 212). The gravel varies in thickness from 18 feet at the two ends of the section to 14 feet near the centre, to which the Gault floor rises gradually from each end.

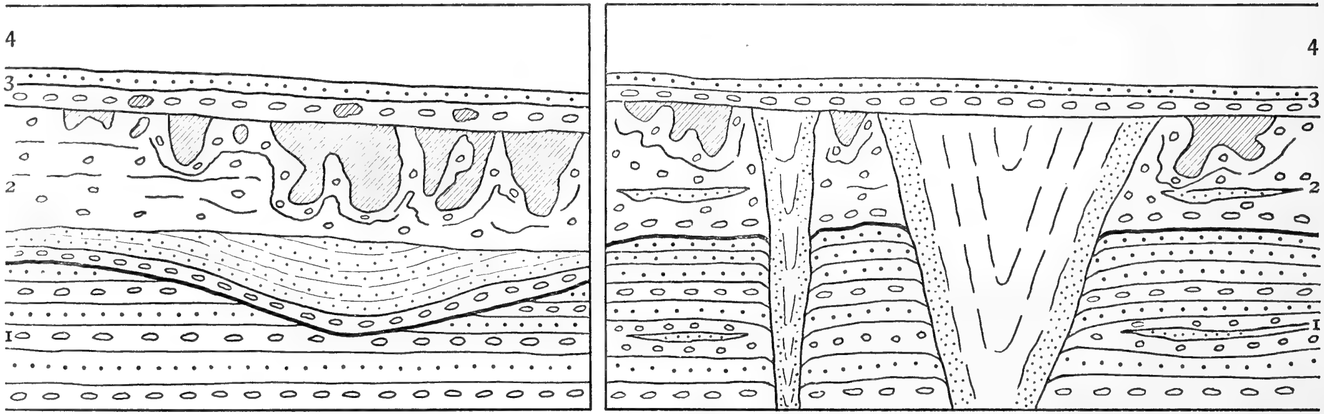
The Gault is usually unaltered, save for a slight weathering for an inch or two at its surface; but in one place in the North Pit a puddled mass of Gault occurred below the basal gravel-seam, and in this puddled material were nodules of 'race' similar to some (described later) in a deposit not far away from the gravel-ridge.

In most sections in the two pits the gravel is readily divisible into two series, of roughly equal thickness, though in the northern corner of the South Pit the upper series was almost certainly absent, a matter of some importance, as will be noted when dealing with the implements.

The lower series is evenly bedded, and the upper more irregularly bedded, often with thick masses devoid of bedding. The two series will be spoken of as 'the lower evenly-bedded' and the 'unevenly-bedded' series. The latter rests unconformably upon the former, and is in many places marked by channels of erosion at the base, as shown in the section. In addition, there are other channels due to subterranean erosion. The former, on the whole, run parallel with the long axis of the ridge, the others more or less at right angles to it, down the slope towards the western valley. The significant feature of these channels of either type is that the upper parts of the latter type, and often also of the former when they are at the top of the succession, are filled with loam.

The usual ferruginous 'pipes' occur at the summit of the deposits immediately beneath the subsoil. They are quite distinct from the loam-channels. In the north-eastern part of the pits the loam-channels also extended upwards to the subsoil. But, as the pit is cut back, a new set of deposits has appeared, consisting of well-bedded sand and gravel 2 to 3 feet thick. Beneath these we find

Fig. 2.—*Sections in the south-western face of the South Pit, Traveller's Rest.* (*Vertical height=19 feet.*)




1 = Lower evenly-bedded series.
2 = Unevenly-bedded series.
3 = Upper evenly-bedded series.
4 = Soil and 'warp.'

The diagonal shading indicates the 'pockets' of loam and sections of 'pipes' from the warp above. The thick line represents the junction between the evenly-bedded and the unevenly-bedded series.

The left-hand section is at the south-eastern end of the south-western face of the South Pit; the right-hand section is about the middle of the same face. There is a gap of many yards between the two sections. The left-hand section shows an erosion-channel at the base of the unevenly-bedded series: it is filled in with a basal gravel overlain by false-bedded sand. The right-hand section shows an underground erosion-channel, with sand and gravel dragged down at the side and loam in the centre. The beds are bent down at the sides of the channels. An incipient channel is shown to the left of the main one.

a set of ferruginous 'pockets' ending abruptly against the base of the overlying sands and gravels, and easily distinguishable in their character from the higher 'pipes' which abut against the subsoil: these are shown in the appended section, fig. 2. The material in the lower 'pockets' is reddish brown, similar in character to, and probably of the same age as, the loam in the subterranean channels. The loam is different from the sand and gravel which occur at the sides and bases, and these loamy masses seem to be folded into the subjacent deposits, as indicated by contortion of the latter as seen in fig. 2.

The evenly-bedded deposits above these loamy masses occur about the top of the ridge between the Cam Valley and the small valley south-west of the Observatory.

In October 1919 one of the loam-filled subterranean erosion-channels was also found to be cut off above by the same sands and gravels, as shown in the same section; it would appear, therefore, that some time elapsed, after the formation of the unevenly-bedded gravels and the loam now filling the channels and 'pockets,' before these highest sands and gravels were laid down.

We find, then, four distinct sets of deposits here, namely: the lower evenly-bedded sands and gravels, the unevenly-bedded sands and gravels, the loams in the channels, and the uppermost thin regularly-bedded sands and gravels, only recently exposed as the pit is being cut backward.

The lower evenly-bedded series consists of deposits of various degrees of coarseness. The base always shows a fairly coarse gravel, with a very clayey matrix derived from the Gault below. Above are alternating gravels of various degrees of coarseness, sands, and light-coloured loams. Big boulders are found in these beds, and, according to the foreman of the pit, chiefly in the basal deposit.

The unevenly-bedded gravels consist of materials very similar to those of the underlying deposits, apart from the irregularity of their stratification, save that massive deposits of gravel with a loamy matrix devoid of stratification are frequent. Lenticular deposits of finely-bedded sand occur at various horizons in the upper series, usually filling small erosion-channels and showing false bedding parallel to the floors of the channels. Many boulders also occur in the unevenly-bedded series, especially in its basal deposit, which is usually a coarse ferruginous gravel.

The third series of deposits—the loams—are chocolate-brown sandy loams with scattered flint-pebbles. Seams of gravel occur in them occasionally. Their occurrence in ordinary erosion-channels is of importance, as indicating that they were deposited not long after the deposition of the uppermost layers of the unevenly-bedded gravels. Their occurrence in the subterranean erosion-channels is of interest, as indicating that they must have been laid down over a wider area than that in which they now occur, but have escaped erosion where let down into these channels. That the channels are due to subterranean erosion is

shown in many ways. The sides are too steep for ordinary subaërial channels in loose material; the deposits on each side bend down towards the channels; and the material of the sides is dragged into the channels, forming selvages. Again, many incipient channels occur in every stage from slight settling of the marginal deposits along a plane of weakness to the fully-formed channel. In one case a channel does not go to the surface, as a ferruginous gravel at the base of the uneven series has resisted the foundering; this channel was cut into the underlying Gault to a depth of 2 feet, and the gravels let down into the Gault, and a stream of water was found flowing at the bottom. Two of these channels were far apart some years ago, but approached each other as the pit-face was cut back. They coalesced as digging proceeded, and have now diverged once more, so that they crossed at the point of coalescence.

As regards the nature of the pebbles in the deposits one need say little, as it is described in the Geological Survey Memoir. They are chiefly flint, usually in subangular pebbles, no doubt broken by water-action and afterwards waterworn in different degrees. They have usually milky-blue surfaces. I mention this, as the surfaces of the implements are often of a very different character, and one which shows that many of them lay on the surface and were exposed to weathering action before they were embedded in the deposits.

The boulders are those of rocks derived from the Boulder-Clay of the area. Their characters have been described in a paper by Mr. R. H. Rastall & Mr. J. Romanes.[1] Among them I have found a few pebbles of Red Chalk, and several are identified with a rock occurring in the Corallian beds of Yorkshire. There are frequent boulders of rhomb-porphyry, usually of small size, but one which I obtained from the South Pit measures $12 \times 11 \times 7$ inches: it is now in the Sedgwick Museum. *Porosphæræ* are occasionally found.

It is quite clear that the lower evenly-bedded and the unevenly-bedded series of deposits were laid down by water; but the origin of the uppermost loams requires elucidation, for the included gravels may be due to inconstant wash on slopes.

The upper evenly-bedded deposits resemble on the whole the lower deposits, but are much thinner. I do not consider that the time that elapsed between the lower evenly-bedded and the unevenly-bedded deposits was very long; but the junction between the latter and the upper evenly-bedded sediments is of a nature which indicates that important changes occurred between the formation of the two series, and this must have taken some time.

We may pass now to the consideration of the fossils, including the implements. Apart from the latter, fossils unfortunately are extraordinarily rare. Implements are relatively abundant, and I have collected with my own hands a large series from the

[1] Q. J. G. S. vol. lxv (1909) p. 246.

piled-up gravel-heaps and one or two *in situ*, and a few more have been found by friends. None have been obtained from the workmen, whom I have purposely kept ignorant of their existence, so that there might be no danger of implements being brought from elsewhere. I may state that I have visited the pits many hundreds of times in the last eight years.

Apart from implements, the only fossils found are of mollusca and vertebrates. The late Prof. H. G. Seeley states[1] that he 'found shells in the gravel under the Observatory,' but these cannot be traced: for many years subsequently no molluscan remains have been found in the Observatory gravels. In 1913, one of the sand-filled channels of contemporaneous erosion near the top of the unevenly-bedded series furnished a number of compound concretions of lime-cemented sands of various sizes, up to over a foot in diameter.

In one of these Mr. K. A. Campbell, of Trinity College, discovered two poor specimens of shell identified by Mr. Hugh Watson as *Pupilla muscorum (?)*. The find is sufficient to prove that the upper gravel, at any rate, contained shells, and the record is useful as an indication of the possibility of discovering molluscan remains in concretions when they do not occur in the normal deposits. Similar concretions occur in sands of the lower series, but have yielded no shells.

Mammalian remains are also very scarce. I can find no bones from these gravels in the Sedgwick Museum, and, during the period when I have closely watched the excavations, only four have been found by the workmen, namely, an astragalus of *Cervus elaphus*, a caudal vertebra of *Rhinoceros ?*, and two teeth of *Equus*. I do not know from which series of deposits these were derived, save that I was informed by the workmen who found one of the horse's teeth, that it came from the basal gravel of the lower evenly-bedded series. Implements, on the other hand, are relatively abundant. It has long been known that they occurred in these gravels. Sir John Evans[2] states that

> 'in the Woodwardian Museum is [a] flake, apparently of Palæolithic date, which was found in gravel near the Cambridge Observatory.'

Two or three others have since been found, and with the former are now in the Sedgwick Museum; but the large series which I have obtained in recent years is sufficient to throw some light upon the ages of the implements, and therefore of the gravels which have yielded them.

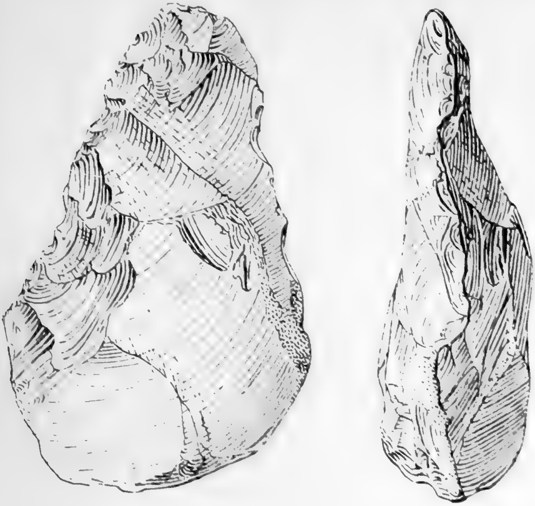
Since 1911 I have obtained nearly 1000 pieces of worked flints, of which more than half were put aside, and several destroyed, though a selection was kept to study questions connected with patination and other matters. About 100 of the remainder may be regarded as implements worked for a definite purpose, but

[1] Q. J. G. S. vol. xxii (1866) p. 475.
[2] 'Ancient Stone Implements of Great Britain' 2nd ed. (1897) p. 538.

Fig. 3.—*Worked flake, blue and buff, with facetted platform.* *Natural size.* (*Traveller's Rest Pit.*)


*a* = Upper surface, *b* = Lower (bulb) surface, *c* = Platform,

Fig. 4.—*Blue-black coup-de-poing, natural size.*



a  b

a = Face.  b = Edge.

[Found *in situ* in unevenly-bedded gravel, Traveller's Rest Pit.]

Fig. 5.—*Grey flake, natural size. (Traveller's Rest Pit.)*

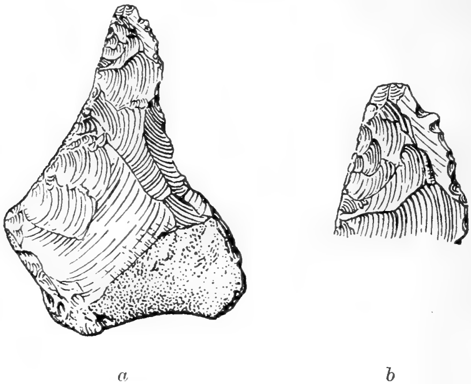
a  b

[a = Upper surface.  b = Lower (bulb) surface.]

many others were doubtless used, although the workmanship is rough.

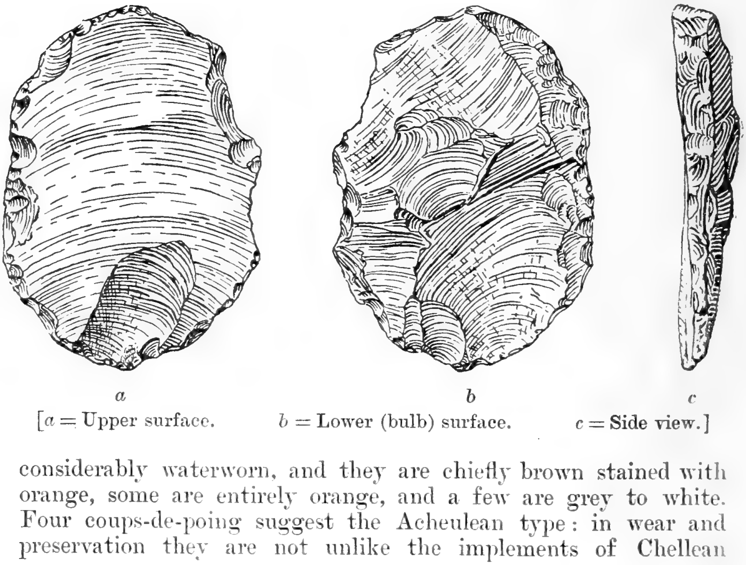
Over twenty coup-de-poing forms are of Chellean type, and there are also scrapers probably belonging to the same period, including a very typical 'Chellean' scraper. Most of these are

Fig. 6.—*'Borer' (grey flint), Traveller's Rest Pit.*



[*a* = Natural size. *b* = Point, twice the natural size.]

Fig. 7.—*Mahogany-brown flake, natural size. (Traveller's Rest Pit.)*



[*a* = Upper surface. *b* = Lower (bulb) surface. *c* = Side view.]

considerably waterworn, and they are chiefly brown stained with orange, some are entirely orange, and a few are grey to white. Four coups-de-poing suggest the Acheulean type: in wear and preservation they are not unlike the implements of Chellean

character, but are thinner, with straighter edges, and of finer workmanship. One specimen deserves particular mention: it is very rough, but almost certainly of human workmanship. In this Mr. Miles Burkitt agrees with me. It is of the character of a rough râcloir with bulb and platform. The interesting feature is that it is made from a silicified oolite which Mr. Rastall has identified with a Yorkshire rock, and it has therefore been formed from a travelled boulder, like some of those mentioned by Sir John Evans from the Brandon district. It is, consequently, of importance as throwing some light on the relationship of Palæolithic Man to the 'Glacial Period.'

In addition to the foregoing there are a large number of implements, which are definitely of Le Moustier character, including small, triangular, thick-butted coups-de-poing, grattoirs, râcloirs (both single and double), and borers (figs. 3–7). Some of the râcloirs appear to be typical Levallois flakes, with facetted striking platforms (fig. 3, p. 216). These implements are, on the whole, less waterworn than those that are referred to an earlier date. They are chiefly milk-blue or grey, sometimes light buff, and in one or two cases mahogany-coloured. A few are ivory white, as is also the case with some of those of presumed earlier date.

Unfortunately, I have obtained very few artefacts *in situ*; one, however, was a small, blue-black, triangular coup-de-poing of Mousterian type, which was found 3 inches above the base of the unevenly-bedded gravels of the North Pit (fig. 4, p. 217). Two flakes found in the same basal gravel of this unevenly-bedded series have the patina so frequent in the implements which I claim to be of Mousterian age.

No implement of the types referred to the earlier periods has been found *in situ*, but one day I found, on a heap just dug from the gravel at the northern corner of the pit, two implements, one a coup-de-poing of Chellean type, the other a definite 'Chellean' scraper of kidney-shape, with the scraping edge on the concave side. These came, therefore, from a part of the pit where, as already stated, the unevenly-bedded gravels appear to be absent.

It would seem, therefore, probable that the Chellean and perhaps the Acheulean types belong to the lower evenly-bedded series, and those of Le Moustier character to the upper unevenly-bedded series: additional evidence is, however, required before this conclusion is definitely accepted. The important point is, that a gravel with implements of Mousterian type occurs at a height of about 40 feet above the deposits containing *Corbicula* and *Hippopotamus*.

There seems to be no doubt that the latter deposits are the older, and this points to a period of aggradation during and after the formation of the *Corbicula* deposits.

It is true that the Observatory Gravels were deposited in a valley which is not the main Cam Valley, but one can hardly suppose that the bottom of the tributary was at a very much higher level than that of the main valley in its vicinity, for the two must have joined at no great distance below Cambridge.

## (c) Clays near the Huntingdon Road.

I briefly referred to these accumulations in my paper in the Proceedings of the Cambridge Philosophical Society, 1917, p. 68. They are found on the land parallel to the Huntingdon Road on the east side of the Observatory Gravel-ridge, and between it and the next gravel-terrace to the east; also to some extent on the west side of the Observatory ridge, on the eastern slope of the minor valley. They have been exposed of recent years in shallow diggings for drains and foundations only. The upper limit of these accumulations is approximately 70 feet above sea-level, and the lower limit apparently between 50 and 60 feet. The material consists of grey clay with many rootlets (probably recent), grains of sand, and small flint-pebbles and frequent derived coprolites. Abundant nodules of 'race' are distributed throughout the material in most places. They vary from a quarter of an inch to nearly an inch in diameter, are white, usually rather friable, and have hollow centres, into which project lobe-like extensions of the calcareous material. The greatest thickness of the accumulation that I have seen was 3 feet 6 inches in a section made when the foundations of a house were being dug at the junction of Storey's Way with the Huntingdon Road. This deposit contained patches of sandy loam 1 to 2 yards long and about 8 inches thick. They occurred in elliptical lenticles arranged in a horizontal band, recalling certain masses figured by Mr. H. Dewey in a paper on 'Researches at Rickmansworth,' by him and Mr. Reginald Smith.[1] There are in places vertical bands of this material above the elliptical patches, as though it had been introduced through fissures, but it is difficult to see how cavities can have been formed of so regular a character.

In all the sections seen the clayey material seems to be roughly stratified, though with sections of so shallow a character it was difficult to be certain of this.

I may note that a similar deposit is well exposed in a pit near the railway between Long Stanton and Over. This also contains the 'race' nodules, and is distinctly stratified. It is mapped by the Geological Surveyors as Boulder Clay.

Unfortunately the relationship of this accumulation to gravels at higher and lower levels has not been established. In 1916 a drain was cut in the field on the side of the road opposite Girton College. This drain was for some distance cut through the Observatory Gravels. About 200 yards south-west of the road, and at a height of about 70 feet above sea-level, the drain passed into a sandy yellow to grey loam, penetrated by rootlets, but containing no 'race.' It resembles the sandy patches seen in the clay elsewhere. The ground had been previously disturbed at the junction between the gravel and the loam, so that the junction was obscure. Below the loam was a sand-bed which may belong

[1] 'Archæologia' vol. lxvi (1915) p. 218. See Bed 2 in fig. 10.

to the Observatory Gravels. Mr. H. V. Sheringham, who superintended the making of the drain, believed that the loam was banked against the gravel. It must, however, be remembered that a clay with 'race' and rootlets occurred below the Observatory Gravels in one place at the North Pit, Traveller's Rest.

It is doubtful whether any fossils have been obtained from the clay. One land-shell seen may have been introduced from the surface. On the heap of clay thrown up from a drain in Christ's cricket-ground, I picked up a dove-grey nucleiform implement, which, however, may also have been forced in from the surface.

The origin of the clay is a matter of considerable importance when we try to establish the sequence of events in this area, and it is to be hoped that further light will be thrown upon these accumulations, which have not hitherto been recognized in the vicinity of Cambridge.

### (*d*) The Upper Barnwell-Village Beds.

These, like the Lower Barnwell-Village Beds, are largely found in the deposits constituting 'the Highest Terrace of the present river-system' of the Geological Surveyors, the upper part of which is usually not much above or below the 50-foot contour-line. On the Histon Road, and also at the Mill-Road Cemetery, the gravels rise to a height of 54 feet, which is approximately that of the lowest level at which the Observatory Gravels are mapped near the Madingley Road; but there is a great spread of gravel north of Cambridge on the west side of the Cam, and it may contain deposits of various ages, some formed during aggradation, others during general valley-deepening. The full history of these deposits awaits elucidation. The sections of which we have much information lie a little below the 50-foot contour-line in Barnwell Village (where there are now no exposures), at Elfleda House, on the Newmarket Road, a quarter of a mile east of the second milestone, and near the junction of the Chesterton and Milton Roads, Chesterton. The gravels of Elfleda House are mapped as belonging to the Ancient River-System, but they grade with the upper gravels of Barnwell Village, and the fossil evidence is in favour of these belonging to that series. If that be so, the difficulty pointed out by the Geological Surveyors, due to the greater height of the 'ancient' gravels on the Observatory ridge, vanishes.

I need not describe the sections in the various pits—this has often been done. It will be remembered that in some places at Barnwell and Chesterton, though by no means generally, *Corbicula* loams occur at the base of the deposits. At Elfleda House they appear to be absent.

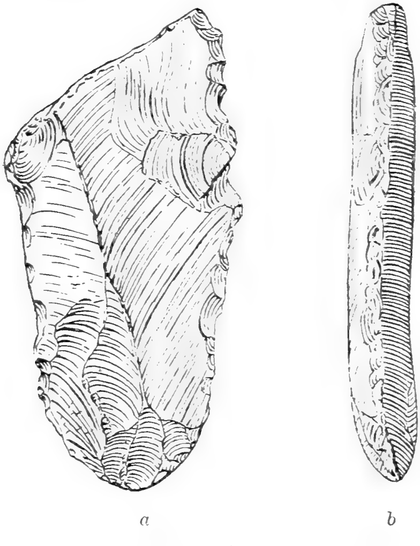
The points to which I wish to draw attention are concerned with the palæontological evidence, which is distinctly in favour of the set of deposits under consideration being referred to the Upper Palæolithic period.

I am not aware that any shells have hitherto been obtained in

the upper gravels of these pits, but mammalian remains have been found in considerable quantity, and among them the mammoth and woolly rhinoceros are very common. We have seen that in the old lists there appears to be an abundance of species probably living at different dates, and further work is required on the mammalian fauna of these deposits. At Elfleda House I have found *Elephas primigenius* and *Cervus elaphus*, and an antler of *C. capreolus* was found there by the Rev. J. G. Walker: these were determined by Mr. C. E. Gray.

The human relics are of particular interest, and require some consideration. Before discussing the finds of the last few years, I may remark that the discovery of a cut bone by the late Rev. J. F. Blake is significant. It was recorded by H. G. Seeley.[1] It is preserved in the Sedgwick Museum, and there seems no doubt as to the human character of the cutting.

Fig. 8.—*Indigo-coloured flake, twice the natural size, (Milton-Road Pit.)*



*a* *b*

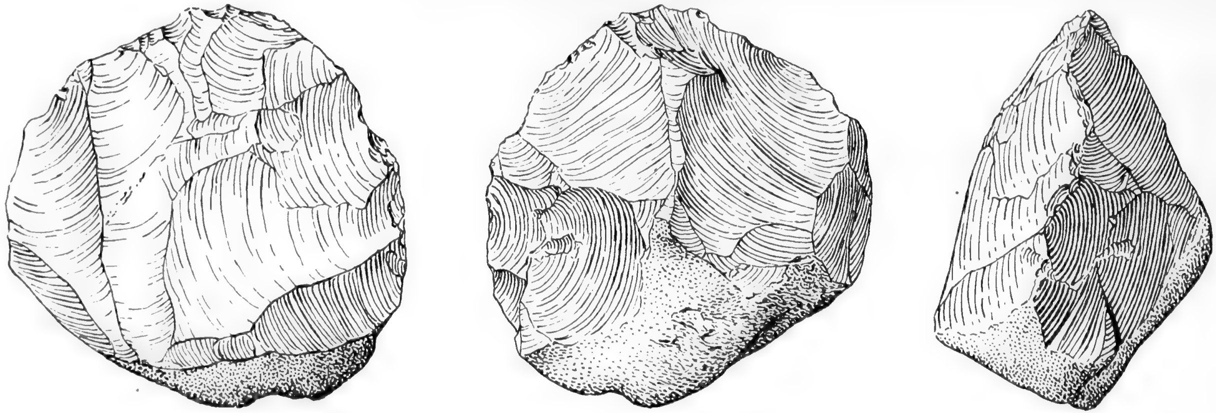
[*a* = Upper surface. *b* = Side view.]

Recently relics of man have been found in the Milton-Road and Elfleda-House Pits. At Milton Road a few very worn flakes are probably derived from earlier deposits. One or two flakes of a bluish colour are in very different condition: one of these is of very great interest. It is the butt-end of a broken flake, $1\frac{1}{4}$ inches long and 1 inch wide. It is highly lustred and of a deep indigo-blue; but the broken surface and some natural chips at the edges are stained of an ochreous colour, also it is waterworn. There is no doubt that it came from the gravel, and is not a surface-piece, as might otherwise be suspected. It is delicately trimmed to a semi-oval outline at the butt-end, and does not resemble any piece known to me of date prior to Upper Palæolithic times. (See fig. 8.)

At Elfleda House worked flints are commoner; but, as the deposit is very loamy, and the implements therefore little waterworn, it is very difficult to distinguish between those referred to the deposits

Q. J. G. S. vol. xxii (1866) p. 477.

Fig. 9.—‘*Tea-cosy*’ *shaped implement, with cortex at the base, dark blue and milk-blue. Natural size.* (*Elfleda-House Pit.*)

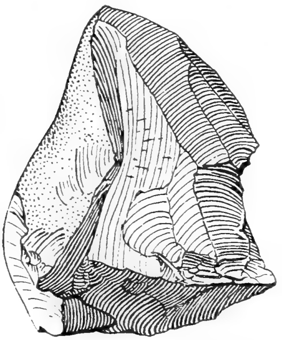


*a* *b* *c*

[*a* & *b* show the two surfaces. *c* = Side view.]

and those which occur on the surface: for the worked flints here, as at Milton Road, have not been found *in situ*, but were picked off the gravel-heaps. Among those which give indications of having been derived from the deposits are two of 'tea-cosy' shape, one of which, however, has the natural cortex at the base (fig. 9, p. 223). These are mottled indigo and grey. A nucleiform implement of milk-blue colour almost exactly matches one found on Christ's cricket-ground, to which reference has already been made (fig. 10). Among other relics is a squamous flake.

Fig. 10.—*Milk-blue nucleiform grattoir, natural size. Elfleda-House Pit.*



A very interesting find in this pit was made by Mr. J. Romanes. It is a 'pot-boiler' and undoubtedly belongs to the deposits. It is waterworn, not only on the cortex but also on the broken surfaces, has manganese efflorescences, and is in parts encrusted with buff-coloured stalagmite.

The discovery of a cut bone, a pot-boiler, and a few artefacts of Upper Palæolithic character, is strong evidence in favour of assigning the containing deposits to one of the Upper Palæolithic periods.

## (*e*) The Higher Downing-Site and Barnwell-Station Deposits.

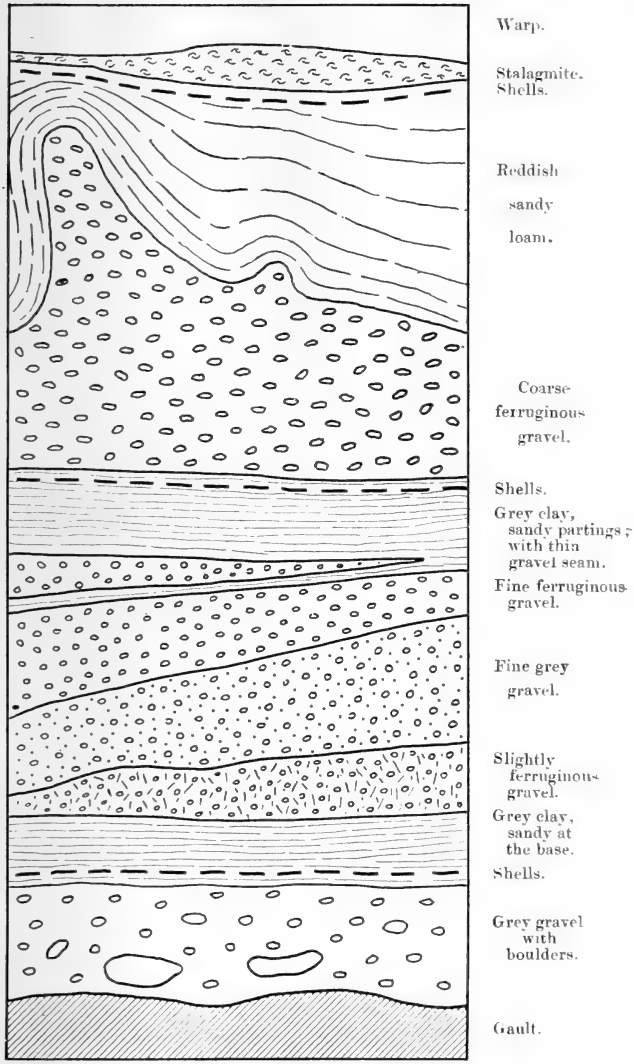
The mollusca obtained from the higher deposits of the Downing Site have been determined by Mr. A. S. Kennard, and the fauna indicates that these beds and those of the Barnwell-Station Pit belong to the same period, though probably they are not exactly contemporaneous.

I will first describe the Downing-Site section. During the War some military trenches were dug on this site, 80 yards south of the south-eastern corner of the School of Agriculture. Prof. A. C. Seward detected a molluscan shell in the loamy deposit in one of the trenches, and accordingly I had a well sunk at the above-mentioned distance from the School of Agriculture.

The section exposed is seen in fig. 11 (p. 225), which was drawn for me by Mr. J. M. Wordie and Mr. F. Debenham. The *Corbicula*-bearing deposits have already been noticed.

The coarse ferruginous gravel is taken as the base of the upper series, and rests with apparent unconformity upon the grey clay beneath. The loams of the *Corbicula* Beds are much lighter in colour than the sandy loam of the upper series, which is of a reddish hue. The upper beds are contorted, as shown in the section.

Fig. 11.—*Section in the well on Downing Site.*




[Vertical scale: 1 inch = 3 feet. Drawn by Mr. J. M. Wordie & Mr. F. Debenham.]

The following mollusca from this loam of the upper series were collected by Mr. C. E. Gray, and determined by Mr. Kennard:—

*Pupilla muscorum* Linné.
*Vertigo parcedentata* A. E. Braun.
*Vertigo edentula* Draparnaud.
*Vertigo antivertigo* Draparnaud?
*Succinea oblonga* Draparnaud.
*Succinea pfeifferi* Rossmässler?
*Limnæa palustris* Müller.
*Limnæa truncatula* Müller.
*Pisidium nitidum* Jenyns.

The height at the top of the ground at the well was determined by Mr. P. Lake to be 35 feet 6 inches above sea-level.

The section at Barnwell-Station Pit has been described in a paper by Miss E. W. Gardner & myself,[1] and we called attention to the existence of peat-seams with an Arctic flora. In that paper attention was drawn to the fact that the deposits extend below the alluvium of the Cam, and that they were probably accumulated in a buried channel. There is evidence that, at the time of the existence of this buried channel, the diversion of the drainage from Cambridge to Somerham to its present direction past Ely occurred, and not at an earlier date. A discussion of this matter, however, requires a description of deposits away from the immediate neighbourhood of Cambridge and must be deferred to another occasion. Both physical and palæontological evidence point to these deposits of Barnwell-Station Pit being the newest Pleistocene deposits of the neighbourhood of Cambridge, having apparently been deposited in a partly-buried channel below the level of the present Cam alluvium.

The probable existence of this channel is also indicated by the deposits mentioned by Prof. Hughes in his paper on 'The Gravels of East Anglia.' He states (p. 40) that

'the Jesus College gravel with Mammoth runs to a depth of some 30 feet below the lower end of Maid's Causeway,'

which is almost flush with the top of the alluvium of Midsummer Common.

I had hoped that the late Mr. Clement Reid would have described the flora of the peat from this pit; but he died before he had completed the study of the plant-remains. He furnished a provisional list of the plants, which is here given. The specimens were washed from the matrix by Miss E. W. Gardner.

*Thalictrum alpinum* Linné.
*Ranunculus hederaceus* Linné.
*Ranunculus lingua* Linné?
*Ranunculus repens* Linné?
*Ranunculus bulbosus* Linné.
*Draba incana* Linné.
*Viola palustris* Linné.
*Silene cœlata* Reid.
*Linum præcursor* Reid.
*Rubus* sp.
*Potentilla erecta* Hampe.
*Potentilla anserina* Linné.
*Hippuris vulgaris* Linné.
*Myriophyllum spicatum* Linné.
*Armeria arctica* Wallr.
*Menyanthes trifoliata* Linné.
*Betula nana* Linné.
*Carpinus Betulus* Linné.
*Salix lapponum* Linné.
*Salix cinerea* Linné.
*Salix repens* Linné.
*Salix herbacea* Linné.
*Salix reticulata* Linné.
*Sparganium minimum* Fr.
*Potamogeton heterophyllus* Schreber.
*Potamogeton densus* Linné.
*Potamogeton obtusifolius* Mertens & Koch.
*Eleocharis palustris* Rœmer & Schultes
*Scirpus* sp.
*Carex incurva* Lightfoot.
*Carex vulpina* Linné?
*Carex* sp.
*Isoëtes lacustris* Linné.

[1] Geol. Mag. dec. 6, vol. iii (1916) p. 339.

I am indebted to Mrs. Eleanor Reid for permission to publish this list, and the brief notes by Mr. Reid which follow. Mrs. Reid has added *Ranunculus amplexicaulis* Linné? to the list.

Mr. Reid states that:

'some curious elongate bodies like small cones, I think, are the droppings of a lemming.'

In discussing the general results of his examination, he remarks:

'I feel no doubt that your Barnwell bed is contemporaneous with the Late Glacial deposits of the Lea Valley. There is a most striking correspondence in the plant-assemblage, which is not the same as that in the Arctic Bed at Hoxne, or that in the Arctic Bed below the Glacial deposits of the Norfolk coast. Indeed, the resemblance between Barnwell and the Lea Valley is so close as to make me think that a very limited Arctic flora probably occupied a wide area in the Eastern Counties during this period. Not only does the same assemblage occur at each locality, but the same Arctic species are missing (*Salix polaris*, *S. myrsinites*, *Dryas*, *Vaccinium* spp., *Arctostaphylos*), although these are found at other horizons in Britain.'

Remains of insects are not uncommon, but it is desirable to obtain more before submitting them to an authority.

Miss Gardner and I collected several shells from this exposure. Some came from the peat-seam, others from a loam, belonging to the same set of deposits. Mr. A. S. Kennard, who kindly identified the shells, tells me that (as would be expected) the fauna is the same in the peat and in the loam. The following were determined by him:—

*Limnæa palustris* var. *diluviana* Kunth.
*Limnæa truncatula* (Müller).
*Limnæa pereger* (Müller).
*Hygromia hispida* (Linné).
*Pupilla muscorum* (Linné).
*Pisidium amnicum* (Müller).
*Planorbis umbilicatus* (Müller).
*Planorbis leucostoma* Millet.
*Succinea oblonga* Draparnaud.
*Succinea pfeifferi* Rossmässler.
*Succinea putris* (Linné).
*Columella columella* (G. von Martens).
*Valvata piscinalis* (Müller).

A list from this pit has already been published by the late Mrs. McKenny Hughes,[1] but shells from more than one deposit seem to have been included; it is, therefore, desirable to publish the above list, for all the deposits exposed at the present time are obviously of one age.

The mammalia recorded by Miss Gardner and myself, as identified by Mr. C. E. Gray from those beds, are the horse, mammoth, woolly rhinoceros, and reindeer: the last-mentioned is fairly abundant.

It will be seen that plants, mollusca, and mammalia all point to Arctic conditions during the formation of these deposits.

## III. Conclusions.

The palæontological evidence points emphatically to the view that the chronological sequence does not coincide with the relative heights of the deposits above river-level, but that in the lower part of the Cam Valley a period of erosion subsequent to the earlier

[1] Geol. Mag. dec. 3, vol. v (1888) pp. 200–202.

Pleistocene period was succeeded by one of general aggradation. Even should the *Corbicula* Beds in the immediate vicinity of Cambridge prove to be newer than the Barrington deposits (and I recognize the possibility of this being the case), the *Hippopotamus* beds of Barrington are generally recognized as being of an early date. But these beds, several miles upstream from Cambridge, are at a height below 70 feet above O. D., whereas the beds containing implements of Mousterian type at the Traveller's Rest, Huntingdon Road, are more than 80 feet above the same datum. These facts in themselves indicate aggradation. Indeed, aggradation to the extent of at least 20 feet is indicated by the thickness of the deposits in the Traveller's Rest Pit itself, and as these deposits occur at a level below the present base of the pit in a westerly direction, aggradation to the extent of about 30 feet is indicated, and a further aggradation of about 15 feet would account for the difference of level between the Milton-Road *Corbicula*-Beds and the deposits at the top of the Traveller's Rest Pit.

Further minor aggradations during the period of general erosion following the main aggradation are indicated. Thus, after the lowering of the water-level to the height of the base of the beds which I have described as the newer Barnwell-Village Beds, a certain amount of aggradation caused the accumulation of these beds at heights of about 30 to 45 feet above O.D. Subsequently to this there was erosion to an unknown depth, forming a channel the base of which passes below the level of the Cam alluvium at Barnwell Station, and another period of aggradation was marked by the accumulation of the Barnwell-Station Beds in this channel.

The occurrence of aggradation in early Palæolithic times is borne out by many observations made outside the area under consideration in this paper. I hope to consider this in greater detail elsewhere. Here I may call attention to the frequent occurrence of Lower Palæolithic implements, some quite unworn, at or below fen-level, as, for instance, at Shrub Hill, Feltwell. The deposits in which these occur are frequently some way below the well-known deposit of High Lodge, Mildenhall, containing implements of Le Moustier type.

As pointed out in my paper in the Proceedings of the Cambridge Philosophical Society, the period of aggradation would correspond with that during which the March and Nar-Valley marine beds were deposited, the latter being at present found at least 50 feet above sea-level.

The occurrence of climatic oscillations is also indicated by the deposits. I do not propose to discuss here the questions as to the relationship of the Palæolithic period to that of the accumulation of the Chalky Boulder-Clay.

Taking into account only the deposits found in the immediate vicinity of Cambridge, there seems proof of a warm period during the time when *Hippopotamus* lived in this district. Succeeding this was a colder period, marked by the incoming of the mammoth

and the woolly rhinoceros, which survived until the end of Palæolithic times. I believe that this period was marked by minor oscillations; but, as no evidence of this has yet been found in the immediate vicinity of Cambridge, I will not dwell upon this subject, and merely note that the period of maximum cold indicated by the fluviatile deposits of Cambridge was that of the beds of Barnwell Station with their Arctic plants and mollusca, and the reindeer.

I hope that in this paper I have shown the existence of a rich field for future work in the basin of the Great Ouse, and have brought together a sufficient number of new observations to aid in the prosecution of such researches.

## Appendix I.

### *The* Non-Marine Mollusca *of the* Cambridgeshire Gravels. By Alfred Santer Kennard, F.G.S., and Bernard Barham Woodward, F.L.S., F.G.S.

### Barrington.

The first list of mollusca from the Pleistocene deposits at Barrington was published by Mrs. T. McKenny Hughes in 1888 and enumerated twenty-four species.[1] In 1911 Prof. T. McKenny Hughes recorded twenty-seven species, and added some details regarding one of the species.[2] In 1913 one of us (B. B. W.) mentioned six species of *Pisidium*, five of which were new records.[3] Several visits have been made to this deposit, and a large amount of material has been washed, the conditions existing at the pit greatly facilitating this work. We are, therefore, now able to register fifty-four species, as follows:—

*Limax maximus* Linné. Five examples.
*L. arborum* Bouchard-Chantereaux. Abundant.
*Agriolimax agrestis* (Linné). Common.
*Milax gagates* (Draparnaud). One example.
*Polita nitidula* (Draparnaud). One example.
*P. pura* (Alder). Two examples.
*P. radiatula* (Alder). Two examples.
*Zonitoides nitidus* (Müller). One example.
*Euconulus fulvus* (Müller). Common.
*Arion* sp. One granule.
*Punctum pygmæum* (Draparnaud). Abundant.
*Pyramidula rotundata* (Müller). Two examples.
*Helicella virgata* (DaCosta). Common.
*H. itala* (Linné). Common.
*Hygromia hispida* (Linné). Abundant.
*Acanthinula aculeata* (Müller). Three examples.
*Vallonia pulchella* (Müller). Common.
*V. excentrica* Sterki. Common.
*V. costata* (Müller). Common.
*Helicodonta obvoluta* (Müller). Two examples.
*Helix nemoralis* Linné (fragments). Common.
*Cochlicopa lubrica* (Müller). Abundant.

[1] Geol. Mag. dec. 3, vol. v (1888) pp. 193–207.
[2] Proc. Geol. Assoc. vol. xxii, pp. 274–75.
[3] B. B. Woodward, 'Catalogue of the British Species of *Pisidium* .... in the British Museum (Natural History), &c.' 1913.

*Pupilla muscorum* (Linné). Abundant.
*Vertigo antivertigo* (Draparnaud). Abundant.
*V. pygmæa* (Draparnaud). Abundant.
*V. angustior* Jeffreys. Five examples.
*Truncatellina minutissima* (Hartmann). Ten examples.
*Clausilia rugosa* Draparnaud. Two apical fragments.
*C. pumila* Pfeiffer. Four fragments.
*Succinea putris* (Linné). Four examples.
*S. pfeifferi* Rossmässler. Abundant.
*S. pfeifferi*, var. *schumacheri* Andreæ. Abundant.
*S. oblonga* Draparnaud. Abundant.
*Carychium minimum* Müller. Three examples.
*Limnæa pereger* (Müller). Abundant.
*L. palustris* (Müller). Ten examples.
*L. truncatula* (Müller). Abundant.
*L. stagnalis* (Linné). Common (fragments).
*Planorbis crista* (Linné). One example.
*P. vortex* (Linné). Six examples.
*P. leucostoma* Millet. Abundant.
*Bithynia tentaculata* (Linné). Two examples (opercula common).
*Valvata piscinalis* (Müller). Common.
*V. cristata* Müller. Two examples.
*V. macrostoma* Stein. One example.
*Pomatias elegans* (Müller).
*Unio* sp. Fragments.
*Corbicula fluminalis* (Müller). Three fragments.
*Sphærium corneum* Linné. Three valves.
*Pisidium amnicum* (Müller). Abundant.
*P. casertanum* (Poli). Abundant.
*P. nitidum* Jenyns. Abundant.
*P. milium* Held. Two valves.
*P. pulchellum* Jenyns. Three valves.
*P. subtruncatum* Malm. Abundant.

No example of *Pomatias elegans* was found by us, so this species is included on the authority of Mrs. Hughes.

The problem of Barrington is a difficult one, and it may be briefly stated as follows :—This deposit has always been considered as of one age, and the mammalian remains which are obtained from the lowest bed indicate a zone similar to that of Grays (Essex), and certainly older than the Barnwell-Abbey gravel. The mollusca, however, do not support this view, for they would appear to indicate a much later horizon. The probable explanation is that two horizons are represented here. *Corbicula fluminalis* has only been found in the lowest bed, with the mammalian remains. Nearly all our material was obtained from above the lowest bed, and we noticed that the freshwater shells were most abundant in the upper part, nor was *Valvata piscinalis* obtained from the lower bed. This is a characteristic fossil which first makes its appearance at Ilford and Barnwell Abbey. The general facies of the mollusca indicates marsh conditions, certainly not lacustrine; while the freshwater species are identical with those from *Chara*-marls. We think that the upper part of this deposit is much later than that of Barnwell Abbey, and is probably a little older than the deposit at Apethorpe (Northamptonshire).

## Barnwell.

The first list of mollusca from the important deposits at Barnwell was published by the Rev. P. B. Brodie in 1844, twenty species being recorded.[1] In 1866 the Rev. E. S. Dewick increased

[1] Trans. Camb. Phil. Soc. vol. viii. pp. 138–39.

the number to forty-four,[1] while in 1872 Mr. Alfred Bell added eleven more species,[2] and in 1878 A. J. Jukes-Browne published a list of fifty-eight species.[3] In 1881 appeared the Geological Survey Memoir, but the list there published is open to severe criticism, and added nothing to our knowledge.[4] Two years later Prof. T. McKenny Hughes gave a list of the species in the Woodwardian Museum.[5] In 1888 Mrs. Hughes published a full description of these deposits, giving a detailed account of the mollusca,[6] while in the same year one of us (B. B. W.) critically revised the previous records, and from an examination of the extant examples extended the list to sixty-seven species, *Clausilia pumila* C. Pfeiffer being figured as British for the first time.[7]

Since then the only additions have been those species of *Pisidium* detected during the revision of that genus.[8] In 1916 the late Prof. T. McKenny Hughes described in much detail the deposits which he considered to be Postglacial. He discussed the conflicting evidence furnished by the contained fossils, and concluded that these beds and their supposed equivalents, which he traced over a large area, formed a well-marked stage in the Pleistocene, for which he proposed the name Barnwellian.[9] In the same year, however, Dr. J. E. Marr & Miss E. W. Gardner published an important paper on the Barnwell-Station Pit, and from the palæobotanical evidence concluded that this deposit was of the same age as the Glacial beds of the River Lea.[10] We had previously arrived at the conclusion that more than one zone was represented at Barnwell, from the fact that certain species of mollusca known from Barnwell indicated a much later zone than the bulk of the species, and it was now clear that at least two zones were represented in the Barnwell gravels. In these circumstances we have deemed it advisable to register the shells from the various sections separately, and with interesting results.

## Barnwell Abbey.

The classic sections at Barnwell Abbey are now 'things of the past,' and, though gravel is still being dug in the neighbourhood, no mollusca are obtainable. In past years, however, when the shells were abundant, the collecting of these fossils was quite fashionable among the students at Cambridge, and numerous collections were

[1] Q. J. G. S vol. xxii, p. 477.
[2] Proc. Geol. Assoc. vol. ii, p. 222.
[3] 'The Post-Tertiary Deposits of Cambridgeshire' Sedgwick Prize Essay for 1876, p. 64.
[4] 'The Geology of the Neighbourhood of Cambridge' Mem. Geol. Surv. Sheet 51 S.W., pp. 106–107.
[5] Geol. Mag. dec 2, vol. x (1883) p. 455.
[6] *Ibid.* dec. 3, vol. v (1888) pp. 193–207.
[7] Proc. Geol. Assoc. vol. x, pp. 355–60.
[8] B. B. Woodward, 'Catalogue of the British Species of *Pisidium*, &c.' 1913.
[9] 'Gravels of East Anglia' Cambridge, pp. 38–58.
[10] Geol. Mag. dec. 6, vol. iii (1916) pp. 339–43.

made. Many of these, doubtless, have been stowed away and forgotten. We have, however, been particularly fortunate during the past few years in ascertaining the existence of some of these collections. Mr. J. R. Le B. Tomlin kindly placed at our disposal his collection from Barnwell Abbey. This was an important one, since several of Mrs. Hughes's records were based on Mr. Tomlin's shells. A selection from this collection was presented to the British Museum (Natural History). Mr. A. J. Jukes-Browne presented to us the series on which his list was based, while Mr. Alfred Bell was the donor of a large series the history of which could not be traced. We were able to acquire a collection made in 1861 by the late Rev. Nicholas Brady, while we are indebted to Mr. J. Wilfrid Jackson, of the Manchester Museum, for an examination of the more critical specimens from a collection presented to that museum. Finally, a large series collected by Mr. Alfred Bell has also passed into our possession. With the exception of some of the shells in the Manchester Museum, all these are clearly from one definite zone, and are identical with the known Barnwell-Abbey shells.

From these sources we are able to add several new records, while increased knowledge of the non-marine mollusca enables us to segregate several species from the previously-recorded aggregates. The list from Barnwell Abbey now numbers eighty species, namely:—

*Limax arborum* Bouchard-Chantereaux. Rare.
*Agriolimax agrestis* (Linné). Rare.
*A. lævis* (Müller). Rare.
*Vitrea crystallina* (Müller). Rare.
*Polita cellaria* (Müller). Rare.
*P. alliaria* (Miller). One example.
*P. nitidula* (Draparnaud). Common.
*P. radiatula* (Alder). Rare.
*Zonitoides nitidus* (Müller). Common.
*Euconulus fulvus* (Müller). Rare.
*Arion* sp. Rare.
*Punctum pygmæum* (Draparnaud). Rare.
*Pyramidula rotundata* (Müller). Rare.
*P. ruderata* (Studer). One example.
*Eulota fruticum* (Müller). Rare.
*Helicella itala* (Linné). Common.
*H. crayfordensis* Kennard & B. B. Woodward. Rare.
*Hygromia hispida* (Linné). Common.
*H. liberta* (Westerlund). Common.
*Acanthinula lamellata* (Jeffreys). One example.
*Vallonia pulchella* (Müller). Common.
*V. excentrica* Sterki. Common.
*V. costata* (Müller). Common.
*Helicigona lapicida* (Linné). Rare.
*Arianta arbustorum* (Linné). Common.
*Helix nemoralis* Linné. Common.
*Ena montana* (Draparnaud). Common.
*E. obscura* (Müller). One example.
*Cochlicopa lubrica* (Müller). Common.
*Azeca goodalli* (Férussac). Common.
*Cæcilioides acicula* (Müller). Rare.
*Pupilla muscorum* (Linné). Common.
*Vertigo antivertigo* (Draparnaud). Rare.
*V. pygmæa* (Draparnaud). Rare.
*V. moulinsiana* (Dupuy). Rare.
*V. angustior* Jeffreys. Rare.
*Truncatellina minutissima* (Hartmann). Rare.
*Balea perversa* (Linné). One example.
*Clausilia rugosa* Draparnaud. Common.
*C. pumila* C. Pfeiffer (Ziegler MS.). Common.
*Succinea putris* (Linné). Common.
*S. elegans* Risso. Common.
*S. pfeifferi* Rossmässler. Common.
*S. oblonga* Draparnaud. Rare.
*Carychium minimum* Müller. Common.
*Ancylus fluviatilis* (Müller). Common.
*Acroloxus lacustris* (Müller). Rare.
*Limnæa auricularia* (Linné). Common.
*L. pereger* (Müller). Common.
*L. palustris* (Müller). Rare.
*L. truncatula* (Müller). Common.
*L. stagnalis* (Linné). Rare.

*Planorbis lævis* Alder. Rare.
*P. crista* (Linné). Rare.
*P. carinatus* (Müller). Rare.
*P. umbilicatus* (Müller). Common.
*P. vortex* (Linné). Rare.
*P. leucostoma* Millet. Common.
*P. contortus* (Linné). Rare.
*P. fontanus* (Lightfoot). Rare.
*Segmentina nitida* (Müller). Rare.
*Physa fontinalis* (Linné). Rare.
*Aplexa hypnorum* (Linné). One example.
*Belgrandia marginata* (Michaud). Rare.
*Bithynia tentaculata* (Linné). Abundant.
*Valvata piscinalis* (Müller). Common.
*Valvata cristata* Müller. Rare.
*Unio pictorum* (Linné). Common.
*U. littoralis* Lamarck. Common.
*Corbicula fluminalis* (Müller). Common.
*Sphærium corneum* (Linné). Rare.
*Sph. mœnanum* Kobelt. Common.
*Sph. lacustre* (Müller). Rare.
*Pisidium amnicum* (Müller). Abundant.
*P. casertanum* (Poli). Common.
*P. nitidum* Jenyns. Rare.
*P. pusillum* Jenyns. Common.
*P. subtruncatum* Malm. Rare.
*P. henslowanum* (Sheppard). Common.
*P. supinum* A. Schmidt. Common.

There is only one record which we consider it advisable to delete: namely, *Vertigo pusilla*. This was based on a single example said to be in the Tomlin Collection, but we failed to find the specimen, and Mr. Tomlin suggests that it was a large *V. angustior*.

Mrs. Hughes has commented on the fact that various species were sporadic in their occurrence, and this is borne out by an examination of the Brady Collection. *Unio littoralis* and *Ena montana* were both absent, while all the species of *Limnæa* and *Planorbis* were sparsely represented. Thus it would appear that the absence of some names from the early lists may have arisen from the fact that they did not occur in the exposures then open.

The general facies of the mollusca indicates climatic conditions similar to those of the present day, or possibly a little warmer.

## East Road, Barnwell.

The late Prof. T. McKenny Hughes described a section behind Rodney Brewery, East Road, Barnwell,[1] and a series of shells obtained from the gravel is now kept in the Sedgwick Museum. The species determined by Mr. Hugh Watson are:—

*Polita nitidula* (Draparnaud).
*Eulota fruticum* (Müller).
*Helicella itala* (Linné).
*Hygromia liberta* (Westerlund).
*H. hispida* (Linné).
*Vallonia* sp.
*Arianta arbustorum* (Linné).
*Helix nemoralis* Linné.
*Ena montana* (Draparnaud).
*Succinea putris* (Linné).
*Limnæa auricularia* (Linné).
*L. pereger* (Müller).
*Planorbis* sp.
*Bithynia tentaculata* (Linné).
*Valvata piscinalis* (Müller).
*Unio littoralis* Lamarck.
*Corbicula fluminalis* (Müller).
*Pisidium amnicum* (Müller).

This gravel is clearly of the same age as that at Barnwell Abbey.

## Milkman's-Lane Pit.

In the British Museum (Natural History) there is a small series of mollusca (C. Birley Bequest), said to be from 'Milkman's-Lane

[1] 'Gravels of East Anglia' Cambridge, 1916, p. 45.

Pit, Cambridge,' a section which we have been unable to locate. The species are :—

*Hygromia hispida* (Linné).
*H. liberta* (Westerlund).
*Arianta arbustorum* (Linné).
*Cochlicopa lubrica* (Müller).
*Ancylus fluviatilis* (Müller).
*Bithynia tentaculata* (Linné).
*Valvata piscinalis* (Müller).
*Corbicula fluminalis* (Müller).
*Pisidium amnicum* (Müller).

This series clearly indicates a zone identical in age with that at Barnwell Abbey.

## Grantchester.

The Pleistocene deposits at Grantchester were described in 1888 by Mrs. Hughes, and the contained mollusca enumerated.[1] She says,

'All the shells in the Woodwardian Museum were obtained from one rich deposit of small extent close to the farm-track, just beyond the S.W. corner of the camp, at a depth of about 5 to 8 feet from the surface. This pit is now filled up, and although there are here and there openings from which sand and gravel are being dug no shells have been found in them.'

The species obtained at Grantchester are sixty-two in number, namely :—

*Vitrea crystallina* (Müller).
*Polita cellaria* (Müller).
*P. nitidula* (Draparnaud).
*P. radiatula* (Alder).
*Zonitoides nitidus* (Müller).
*Euconulus fulvus* (Müller).
*Punctum pygmæum* (Draparnaud).
*Pyramidula rotundata* (Müller).
*Eulota fruticum* (Müller).
*Helicella itala* (Linné).
? *H. striata* (Müller).
*H. crayfordensis* Kennard & B. B. Woodward.
*Hygromia hispida* (Linné).
*H. liberta* (Westerlund).
*Acanthinula aculeata* (Müller).
*Vallonia pulchella* (Müller).
*V. excentrica* Sterki.
*V. costata* (Müller).
*Helicodonta obvoluta* (Müller).
*Helicigona lapicida* (Müller).
*Arianta arbustorum* (Linné).
*Helix nemoralis* Linné.
*Ena montana* (Draparnaud).
*E. obscura* (Müller).
*Cochlicopa lubrica* (Müller).
*Azeca goodalli* (Férussac).
*Cæcilioides acicula* (Müller).
*Pupilla muscorum* (Linné).
*Vertigo antivertigo* (Draparnaud).
*V. pygmæa* (Draparnaud).
*V. moulinsiana* (Dupuy).
*Vertigo angustior* Jeffreys.
*Clausilia rugosa* Draparnaud.
*C. pumila*, C. Pfeiffer (Ziegler MS.).
*Succinea putris* (Linné).
*S. elegans* Risso.
*S. oblonga* Draparnaud.
*Carychium minimum* Müller.
*Ancylus fluviatilis* (Müller).
*Acroloxus lacustris* (Müller).
*Limnæa auricularia* (Linné).
*L. pereger* (Müller).
*L. palustris* (Müller).
*L. truncatula* (Müller).
*L. stagnalis* (Linné).
*Planorbis lævis* Alder.
*P. crista* (Linné).
*P. carinatus* (Müller).
*P. umbilicatus* (Müller).
*P. vortex* (Linné).
*P. leucostoma* (Miller).
*P. contortus* Linné.
*Physa fontinalis* (Linné).
*Aplexa hypnorum* (Linné).
*Bithynia tentaculata* (Linné).
*Valvata piscinalis* (Müller).
*V. cristata* Müller.
*Unio pictorum* (Linné).
*U. littoralis* Lamarck.
*Corbicula fluminalis* (Müller).
*Sphærium corneum* (Linné).
*Pisidium amnicum* (Müller).

[1] Geol. Mag. dec. 3, vol. v, p. 197.

There can be no doubt that this deposit is of the same age as that at Barnwell Abbey, for the lists are nearly identical, the numerical superiority of the latter having arisen from the fact that far more collecting was done there.

## Downing Section.

During the war military trenches were dug about 150 yards from the Sedgwick Museum, and, seeing the importance of the sections exposed, they were deepened through the efforts of Prof. J. E. Marr. The section exposed was as follows:—

| | *Feet.* |
|---|---|
| (1) Surface-soil | 1 |
| (2) Warp | $2\frac{1}{2}$ |
| (3) Buff sandy loam | 3 |
| (4) Fairly coarse gravel | 2 |
| (5) White marly clay | 1 to $1\frac{1}{2}$ |
| (6) Fine gravel | 2 seen |

The shells occurred in two distinct horizons: one at the top of No. 3, and one near the top of No. 5. We are indebted to Prof. Marr for the above details, and for the opportunity of examining the specimens. The upper layer yielded:—

*Pupilla muscorum* (Linné). Common.
? *Vertigo antivertigo* (Draparnaud). One example.
*V. parcedentata* (Al. Braun). Five examples.
*Columella edentula* (Draparnaud). Two examples.
? *Succinea pfeifferi* Rossmässler. Four examples.
*S. oblonga* Draparnaud. Common.
*Limnæa palustris* (Müller). Common.
*L. truncatula* (Müller). Common.
*Pisidium nitidum* Jenyns. One valve.

An apparently recent example of the burrowing species *Cæcilioides acicula* (Müller) also occurred.

The lower horizon furnished six species, namely:—

*Hygromia hispida* (Linné). Two examples.
*Valvata piscinalis* (Müller). Four examples.
*Corbicula fluminalis* (Müller). One valve.
*Sphærium corneum* (Linné). One valve.
*Pisidium amnicum* (Müller). One valve.
*P. henslowanum* (Sheppard). One valve.

This is perhaps the most important section in these gravels, since stratigraphical evidence is available to check palæontological conclusions. The lower horizon is clearly of the same age as the Barnwell-Abbey bed; but the facies of the upper one has no exact parallel in the neighbourhood. It is probably later than the upper bed at Barrington, though earlier than that at Barnwell Station.

## Trumpington.

We are again indebted to Prof. Marr for the details of this section, and for the opportunity of examining the mollusca, which are now in the Sedgwick Museum. The shells were obtained from the bottom of the section, at a depth of 11 feet. Eleven species are represented, namely:—

*Helicella itala* (Linné). Common.
*H. crayfordensis* Kennard & B. B. Woodward. Common.
? *H. striata* (Müller). One example.
*Hygromia hispida* (Linné). Common.
*Arianta arbustorum* (Linné). Six examples.
*Helix nemoralis* Linné. One fragment.
*Succinea pfeifferi* Rossmässler. One example.
*Succinea oblonga*, Draparnaud. Two examples.
*Valvata piscinalis* (Müller). Two examples.
*Pisidium amnicum* (Müller). Six valves.
*P. henslowanum* (Sheppard). One valve.

These shells would indicate that the lowest bed is contemporary with the Barnwell-Abbey gravel, or possibly a little later in age.

## Barnwell Station.

In 1888 Mrs. Hughes described and figured the section exposed in the gravel-pit near Barnwell Station,[1] and mentioned eighteen species of mollusca. She discussed the relative ages of this deposit and of the Barnwell-Abbey gravel, and concluded:

'The lie of the ground seems to point to their being part of the same mass, but the character of the deposits seems to indicate that, though they belong to approximately the same age, they were nevertheless laid down under somewhat different conditions.'

The published list of the mollusca would appear to support this view, except that Mrs. Hughes notes that *Pupilla muscorum* [= *Pupa marginata*] is very common, a feature which, as we now know, characterizes a much later stage than that of Barnwell Abbey.

In 1916 Prof. Marr & Miss E. W. Gardner described the sections, which had been greatly enlarged since the previous paper. They recorded four species of mollusca, and from palæobotanical evidence concluded that this gravel was of the same age as the Arctic Beds at Ponders End.[2] In the following year Prof. Marr again referred to this pit, and emphasized its late Pleistocene age.[3] We had previously seen, through the courtesy of Mr. J. Wilfrid Jackson, molluscan remains from 'Barnwell' which included examples of *Columella columella* (G. von Martens), a species characteristic of the late Pleistocene (Arctic Beds), and we had concluded that the Barnwell gravels represented more than one horizon, a conclusion which was now verified.

[1] Geol. Mag. dec. 3, vol. v, p. 196.
[2] *Ibid.* dec. 6, vol. iii, pp. 339–43.
[3] Proc. Phil. Soc. Camb. vol. xix, pp. 64–71.

The series of mollusca obtained by Prof. Marr was kindly forwarded to us, and we were able to identify thirteen species, namely:—

*Hygromia hispida* (Linné). Six examples.
*Pupilla muscorum* (Linné). Abundant.
*Columella columella* (G. von Martens). Two examples.
*Succinea* cf. *grœnlandica* Beck. One example.
*S. pfeifferi* Rossmässler. Common.
*S. oblonga* Draparnaud. Common.
*Limnæa pereger* (Müller). Common.
*Limnæa palustris* (Müller). Five examples.
*L. truncatula* (Müller). Two examples.
*Planorbis umbilicatus* (Müller). One example.
*Pl. leucostoma* Millet. One example.
*Valvata piscinalis* (Müller). Three examples.
*Pisidium amnicum* (Müller). One example.

It is perhaps advisable to ignore the previous records not confirmed in the above list.

The examples are not so dwarfed as those from the Arctic Beds of the Lea Valley; nevertheless, they clearly belong to that stage, and indicate similar climatic conditions.

## Minor Deposits.

Prof. Hughes recorded *Corbicula fluminalis* from the gravel in the railway-cutting north of Shelford.[1]

S. V. Wood[2] noted that

'Mr. Harmer has found the freshwater shell *Corbicula* [*Cyrena*] *fluminalis* in numbers in this gravel [March] associated with *Cardium edulis* [*sic*] and other marine shells; an association corresponding to that which occurs in the Hessle gravel at Kelsea Hill in Yorkshire.'

S. H. Miller & S. P. J. Skertchley again recorded this species in 1878, and added that it also occurred at Chatteris, Whittlesea, and Normanslandhirme.[3] There is another record of this species from Chatteris[4]; while *Unio tumidus*, *Bithynia tentaculata*, and *Valvata piscinalis* are cited from the March gravels. We can confirm the record of *Corbicula fluminalis* from March, from examples in our collection. Prof. Marr has called our attention to the fact that an example of this species, obtained at Manea, north-west of Ely, by the late Prof. Hughes, is in the Sedgwick Museum.

## Notes on some of the Species.

VITRINA PELLUCIDA (Müller).

The single example of this species was obtained from the interior of a specimen of *Arianta arbustorum* (Linné), from Barnwell Abbey. It is the oldest record for the species, for the examples

[1] 'Gravels of East Anglia' Cambridge, 1916, p. 46.
[2] 'Crag Mollusca' 2nd Suppl., Pal. Soc. Monogr. 1879, p. 53.
[3] 'Fenland Past & Present' p. 539.
[4] 'The Geology of South-West Norfolk & North Cambridgeshire' (Sheet 65) Mem. Geol. Surv. 1893, p. 110.

from the Forest Bed (Cromerian) of West Runton referred to this species do not belong to that form.

Polita nitidula (Draparnaud).

All the examples of this species are small though mature, and are much smaller than recent ones.

Helicella virgata (Da Costa).

Only known from Barnwell, where it is not uncommon. The examples exhibit but little variation, and are quite as large as average recent specimens. As a Pleistocene fossil, *H. virgata* is only known from Ilford and Grays (Essex), Portland (Dorset), Santon and Chudleigh (Devon).

Helicella itala (Linné).

The examples from Barnwell Abbey are rather small, and are decidedly flat, while those from Barrington are distinctly higher in the spire.

Helicella striata (Müller).

We have provisionally referred to this species a single example from Trumpington; but Mr. Hugh Watson informs us that a similar shell was obtained from Grantchester, and is now in the Sedgwick Museum. This, or a closely-allied form, occurs in the Pleistocene of Woodston (Huntingdonshire), and in that of Cuxton and Halling (Kent).

Hygromia hispida (Linné).

Three well-marked forms, without intermediates, of this group occur in these deposits.

(1) A very flat form and always white. It occurs at Barnwell Abbey, Grantchester, and Trumpington. Elsewhere in the Pleistocene it is known from Swanscomb and Crayford (Kent), Clevedon Cave (Somerset), and Fisherton (Wiltshire).

(2) The form that is always high-spired, with a small umbilicus, and reddish in colour. It occurs at Barnwell Abbey and Grantchester, while elsewhere in the Pleistocene it is known from Ilford (Essex), Apethorpe (Northamptonshire), Swanscomb (Kent), and Stutton (Suffolk). Examples from Barnwell Abbey were submitted to the late Dr. O. Bœttger, of Frankfort, who identified them as *H. sericea* Draparnaud (*non* Müller=*liberta* Westerlund), and we have recorded them under that name. It may be noted that both these forms probably occur in the Forest Bed (Cromerian) of West Runton; but, since only immature examples have been seen, it is impossible to speak definitely.

(3) A form, as a rule, intermediate in the height of the spire between 1 and 2. High-spired examples are not uncommon; but in these the umbilicus is always larger than in *H. liberta*. In colour they are whitish, but never the dead white of the first group. They occur at Barrington, Trumpington, and Barnwell Station.

It would thus appear that 1 & 2 are the oldest forms, while 3 made its appearance at a much later date. Though we have referred 1 & 3 to *H. hispida*, in all probability the former has no genetic relationship to the living form, the ancestral form being No. 3.

HELICODONTA OBVOLUTA (Müller).

In the English Pleistocene this species is only known from these deposits, one example having been found at Grantchester and two obtained by us at Barrington. In a living state in these islands it is only known from Hampshire, West Sussex, and possibly Surrey.

ARIANTA ARBUSTORUM (Linné).

This species was very common at Barnwell Abbey, and, as usual, it varied considerably in size; but the majority of the examples were high-spired. One abnormal specimen in our collection measures 23·4 mm. in height by 20 mm. in breadth, and is a very heavy shell, the thickening being very marked at the aperture. It is, however, matched by a similar example from Upnall, Ilford, although this last is a thin shell. This difference in texture probably arises from the environment, for the soil on which the Cambridge example lived was calcareous, while the Ilford individual lived on a non-calcareous soil.

HELIX NEMORALIS Linné.

The examples from Barnwell Abbey are well developed, and usually the colour-bands are preserved. We have noted the following band formulæ:—

12345 (12345), 123 (45), 00345, 003 (45), and 00000.

VERTIGO PARCEDENTATA (Al. Braun).

The occurrence of this species at the Downing Section is of extreme interest. It is now known from Apethorpe, Northamptonshire (late Pleistocene), Ponders End and Angel Road, Middlesex (Glacial), and Elie, Fifeshire (Early Holocene). It has been figured by us in this Journal.[1]

CLAUSILIA PUMILA C. Pfeiffer (Ziegler MS.).

This species was fairly common at Barnwell Abbey and Grantchester, but rare at Barrington. It is not uncommon in the remarkable Pleistocene deposit at Woodston, near Peterborough.

SUCCINEA PUTRIS (Linné).

Common at Barnwell Abbey, where it attained a large size. Many examples may be referred to the var. *limnoidea* Pic. Rare, and then only of small size, at Barrington,

SUCCINEA ELEGANS Risso.

Common and well developed at Barnwell Abbey.

[1] Q. J. G. S. vol. xlviii (1912) pl. xvi, figs. 6 *a* & 6 *b*.

Succinea pfeifferi Rossmässler.

Common at Barnwell Abbey and abundant at Barrington, where the variety *schumacheri* Andreæ was common.

Succinea oblonga Draparnaud.

Very common at Barrington and common at Barnwell Station. All the examples are, however, typical. There is a marked absence of the var. *agonostoma* Kust. found at Ilford (Essex), Stutton (Suffolk), and Woodston (Northamptonshire).

Limnæa palustris (Müller).

The examples from Barrington are dwarfed. The specimens from Barnwell Station may be referred to the var. *diluviana* Andreæ.

Limnæa truncatula (Müller).

All the examples of this species are small. Recent examples are often much larger.

Bithynia tentaculata (Linné).

The specimens from Barnwell Abbey are, as a rule, large, with an inflated body-whorl, and approximate to recent examples.

Unio littoralis Lamarck.

Common at Barnwell Abbey. The shells are, however, smaller than those from Crayford and Clacton, but larger than Swanscomb specimens.

Corbicula fluminalis (Müller).

Common at Barnwell Abbey and Grantchester; rare at Barrington, where it only occurs in the lowest bed. The examples are small, but this is probably due to their environment, for English Pleistocene shells from gravels are always small. The largest examples occur in the brickearths of Crayford and Stutton, and these are much larger than any Continental Pleistocene specimens that we have seen.

## Conclusions.

'Strata are known by their contained fossils' is a statement as true of gravels as it is of limestones. In the neighbourhood of Cambridge are a series of gravels which, on stratigraphical evidence, have been considered to be of one age; yet an examination of the mollusca shows clearly that several horizons are represented, covering a vast period of time.

The oldest is the basement-bed at Barrington, yielding mammalian remains which may well be correlated with the older brickearths of Grays. The next stage is represented by Barnwell Abbey, East Road, Barnwell, Milkman's Lane, Grantchester, and the lower bed of the Downing Section. They are the equivalents of the Upnall (Ilford) deposits in the Thames Valley. Trumpington may belong to this stage, or, more probably, may be slightly newer.

Barrington (upper layers) is certainly later, and has no exact equivalent in the Thames Valley. It is probably later than Crayford.

A still later stage is represented by the upper layer at the Downing Section; while the last stage, Barnwell Station, is the equivalent of the Arctic Beds of the Lea Valley. There has been considerable divergence of opinion as to whether these gravels are Preglacial, Interglacial, or Postglacial, and the literature relating to this is voluminous; but there is no need to enter into the various arguments that have been adduced.

If the deposits are judged from a palæontological standpoint, there is only one conclusion, and that is that, with the exception of the Barnwell-Station beds, they are all Preglacial. It is, indeed, a noteworthy fact that, wherever stratigraphical evidence is available, the Arctic Bed is always above the other Pleistocene deposits. In no case is an Arctic Bed succeeded by deposits of undoubted Pleistocene age indicating genial conditions. Hence it is clear that there has been only one cold period, and this occurred at the close of the Pleistocene.

## Appendix II.

### Notes *on the* Implements.

By Miles Crawford Burkitt, M.A., F.G.S.

In considering those implements of undoubted human manufacture that Prof. Marr has discovered at the Traveller's Rest gravel-pit, two more or less distinct series seem to be present:—

(*a*) There is a series of much waterworn implements, which are in some cases stained deep ochreous-brown and in other cases greenish bluish-brown. These are undoubtedly of Lower Palæolithic age. Without faunal evidence—that is, alas, completely lacking—it would be difficult to say how much is Acheulean and how much Chellean. At any rate, forms of undoubtedly Lower Palæolithic age are common.

There are both large and small coups-de-poing, side scrapers with a Chellean trimming, worked flakes, etc. Many of these very much recall the industry at 'Three Hills.' There are also a number of unworked triangular flakes that have been struck off by a blow which leaves a good bulb of percussion: similar flakes are found at 'Three Hills.' A rough sort of core-scraper has also been found, which, owing to its deep ochreous-brown patina, would belong to this series.

There is, too, a small coup-de-poing with the twisted sides that are so typical of the Acheulean period.

(*b*) A series has also been found which, on examination, leaves a totally different impression. Whenever implements of this series have been obtained *in situ*, they come from upper levels of the pit. The rest (as also those of series *a*) have been collected from heaps left by the workmen.

This series is usually bluish and is much less waterworn. No

large coups-de-poing occur, only little tiny varieties, one of which was actually found *in situ* in the upper beds. These small coups-de-poing may be compared with a small example which, from its patina, has been placed in the first series. This latter is, however, very much more waterworn, and the trimming is different. A few borers have been found, as well as side scrapers, and some small flat oval flakes. It should also be noted that facetted striking platforms occur, and attempts, often not very successful, have been made to remove the bulb of percussion.

It seems safe to conclude that in the case of Series *a* we are dealing with a typical Lower Palæolithic industry, composed probably of an admixture of Chellean and Acheulean forms. The admixture has certainly been made by water, producing the waterworn appearance that has been already noted.

Series *b* does not seem far removed in time from Series *a*, as is shown by a comparison of the small coups-de-poing from the two series. It may be of late Acheulean, or more probably of Lower Mousterian age. This would bear out the little stratigraphical work that has, so far, been possible. Series *a* can be certainly compared with the industry at 'Three Hills.' Series *b* may be of the same age as the implements of 'High Lodge.'

With regard to the finds of later date from the Milton Pit, etc., I can only say that there is nothing to add to Prof. Marr's statement of the case. The finds are few, and it is to be hoped that further evidence will be forthcoming. However, the general appearance of the implements suggests an Upper Palæolithic age. It is unfortunate that the layer from which the well-worked core-scraper came cannot be demonstrated for certain. The difference between the derived waterworn implements of earlier age and those of the same age as the deposit is very marked.

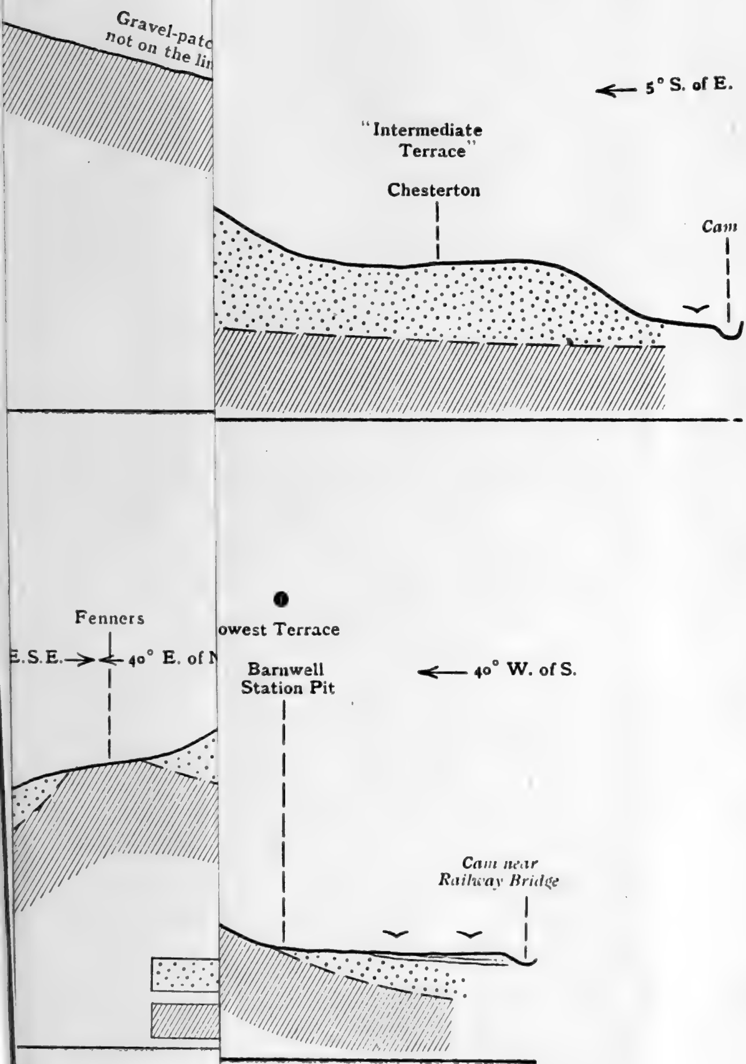
## EXPLANATION OF PLATE XI.

Fig. 1. Section from Elfleda House, near Barnwell, to the Madingley Road.
2. Section from Barnwell Station to Newnham.

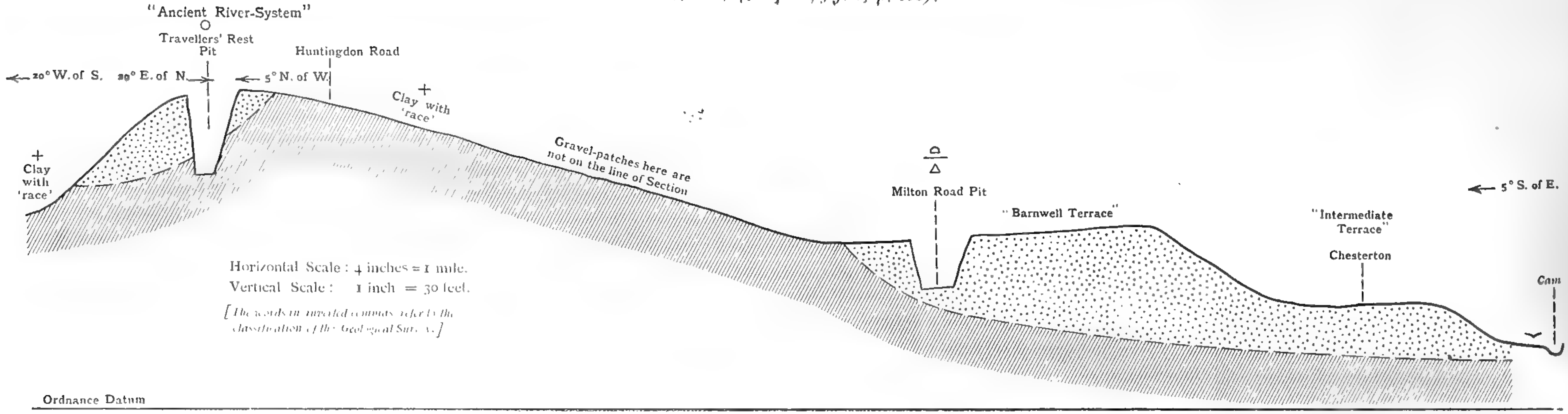
[Scales of both sections: horizontal, 4 inches to 1 mile; vertical, 1 inch to 30 feet.]

## Discussion.

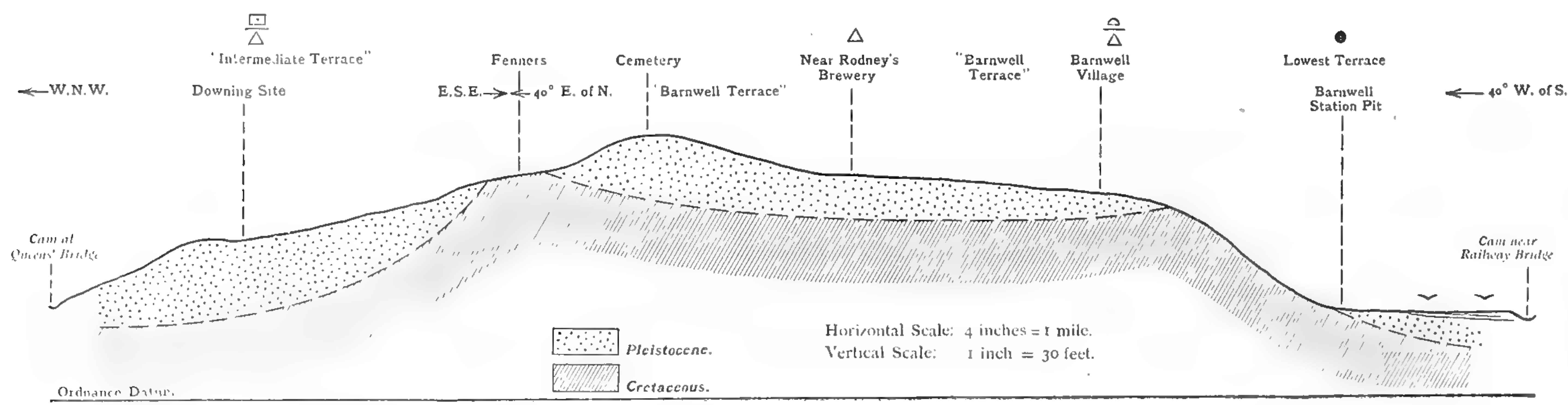
Sir William Boyd Dawkins welcomed the paper as the first instalment of a series on the Pleistocene strata of the district of Cambridge. He was glad that the Author, in dealing with the stone implements of the various deposits, divided them up into the three Early Palæolithic 'types' of Chelles, St. Acheul, and Le Moustier, without falling into the common mistake of treating them as characteristic fossils for the purpose of classifying the strata into those three periods. In the speaker's opinion, from the geological point of view, all three are of the same approximate age, and their division by the archæologists into three successive periods in France will not apply to England. Here all three types


Gravel-patc
not on the lin
← 5° S. of E.
"Intermediate
Terrace"
Chesterton
Cam
Fenners
E.S.E. → ← 40° E. of N
owest Terrace
Barnwell
Station Pit
← 40° W. of S.
Cam near
Railway Bridge

*Section 1 (see plan, fig. 1, p. 205).*




*Section 2 (see plan, fig. 1, p. 205).*



occur in close association in the same gravel-pits, throughout the eastern and southern counties.

The Author points out that the oldest deposits treated in his paper are those at Barrington, with remains of *Rhinoceros merkii* and *Hippopotamus*. There is, however, an older group, represented by a small collection of bones and antlers, as yet undetermined, in the Sedgwick Museum, which, shortly before his death, Prof. Hughes showed to the speaker. Among these are three or four antlers of *Cervus arvernensis*, a Pliocene deer found in Auvergne and also in the Forest Bed of Norfolk, and not recognized in any other British locality. When this fauna has been worked out, it is likely to link up that of the Forest Bed with that of Barrington, and thus fill a blank in the early history of the Pleistocene Epoch.

Mr. REGINALD SMITH thought that the paper would be an inspiration, not only to those present, but to others interested in the subject. Names had been borrowed from the French classification for the various types of implements; but, seeing that the system had now been tested for thirty-five years, a further step might be taken with confidence, and the Chelles type assigned to the Chelles period, and the rest in order. The series exhibited comprised rolled specimens of the Drift types, probably all from the lower (horizontal) strata of the Observatory gravels, unlike certain other sites where the Chelles implements lay unrolled in the undisturbed lower levels, and rolled specimens of St. Acheul type occurred in the upper levels. Hence there was probably no orderly deposition in the present case till Le Moustier times. These later flakes doubtless came, like the small hand-axe, from the disturbed beds above, and the still later Cave types from the well-defined layer below the soil: among the latter should be noticed the 'cosy' or segmental tool and the undercut conical plane. He had been impressed by the quantity of big boulders in the pit, and questioned whether they were river-borne. The Author's committee was a welcome innovation, and would have much to do, as the enquiry could not be confined to the neighbourhood of Cambridge, but must eventually deal with other deposits of implements in gravel, as at Warren Hill near Mildenhall and at Kennet near Newmarket.

Mr. W. WHITAKER called attention to the difficulties that arose in trying to differentiate gravels, deposits of an irregular character and changing composition, such that sections at spots no great way apart might show beds unlike in composition. There was a danger, therefore, of taking as signs of deposits of differing age what might be only differences of character in one deposit. He doubted also whether the irregularities, of unconformable appearance, shown by some of the sections, pointed to more than somewhat rapid changes in the nature of the deposit, changes of current, etc.

The revision of the mapping of many gravels was needful, and he was glad that the Author had taken up the task in the Great Ouse Basin. He could not wish him better than in hoping that he would live to finish the work.

Mr. M. C. Burkitt ventured to disagree with Sir William Boyd Dawkins's statement that the Lower Palæolithic could not be divided into periods by using the contained implements as fossils. The speaker had done much work abroad, in the field, with H. Breuil, H. Obermaier, and others, and he could testify that, where the implements had not been rolled into a deposit subsequently by water action, such divisions were possible. Chellean types do indeed develop up into Acheulean, but the Mousterian was quite another culture. With regard to the Barnwell-Station gravels the speaker was disinclined to ascribe to them a Würmian age. He preferred to consider them as of Bühl age (that is, equivalent in time to the Magdalenian civilization of France, which perhaps never really reached England). At that time the reindeer (whose bones occur in the Barnwell-Station gravel) arrived as far south as Mentone. It was certainly a cold, probably a dry period.

The President (Mr. G. W. Lamplugh) desired to express the satisfaction with which the paper would be received by all students of our Pleistocene deposits, as a sign that the re-examination of these difficult beds in a critical area had been undertaken by the Author. It was comparatively easy to frame an idea of the course of events during the period in our eastern and western coastal belts, but the synchronous conditions in the Midland area were evidently much more complex and variable, and the evidence required much further investigation. In this region it is believed that the invasion of the ice was a comparatively short event and was probably not simultaneous over the whole area. Many of the gravels and other drainage phenomena bore testimony to abnormal conditions during Late Glacial times, brought about by the floods of thaw-water poured across the area from both sides, in addition to its local drainage. The speaker agreed that the level at which the gravels were found did not afford conclusive evidence as to relative age. He thought, also, that some of the peculiarities of the fauna and flora might be due to the co-existence in the neighbourhood of tenants of areas which, having escaped actual glaciation, differed widely from those that alone had been able to establish themselves on the desolated tracts of cold clay and gravel left by the retreating ice. But, as the Author had confined himself so strictly in this paper to the statement of facts, it was perhaps premature at present to discuss their interpretation.

The Author thought that the deposit mentioned by Sir William Boyd Dawkins was one which Prof. Hughes had found close to Newmarket Station. His own paper dealt strictly with a tract covering a radius of about 2 miles from Cambridge: here no Boulder-Clay occurred, and he had abstained from treating of the relationship of the Pleistocene gravels to the Boulder-Clay, though he proposed to discuss their relations elsewhere. He would, however, call attention to the existence of large boulders derived from the Boulder-Clay, which were found in the gravels of the Traveller's Rest.

His paper dealt especially with the question of palæontological sequence.

[**June 17th, 1920.**]

# CONTENTS.

PAPERS READ.



[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

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**Vol. LXXV.** **No. 300.**
Part 4.

THE

# QUARTERLY JOURNAL

OF THE

# GEOLOGICAL SOCIETY.



EDITED BY

THE PERMANENT SECRETARY.

**[With Seven Plates, illustrating Papers by Prof. S. J. Shand and Dr. A. Gilligan.]**

August 17th, 1920.

LONDON:

LONGMANS, GREEN, AND CO.

PARIS:—CHARLES KLINCKSIECK, 11 RUE DE LILLE.

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### Session 1920–1921.

| | | |
|---|---|---|
| | 1920. | |
| Wednesday, | November | 3*—17* |
| ,, | December | 1 —15* |
| | 1921. | |
| ,, | January | 5*—19* |
| ,, | February (*Anniversary Meeting*, Friday, February 18th) | 2*—23* |
| ,, | March | 9 —23* |
| ,, | April | 20* |
| ,, | May | 4 —25* |
| ,, | June | 8 —22* |

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

12. *A* RIFT-VALLEY *in* WESTERN PERSIA. By S. JAMES SHAND, D.Sc., F.G.S., Professor of Geology in the University of Stellenbosch, South Africa. (Read December 17th, 1919.)

[PLATES XII–XIV.]

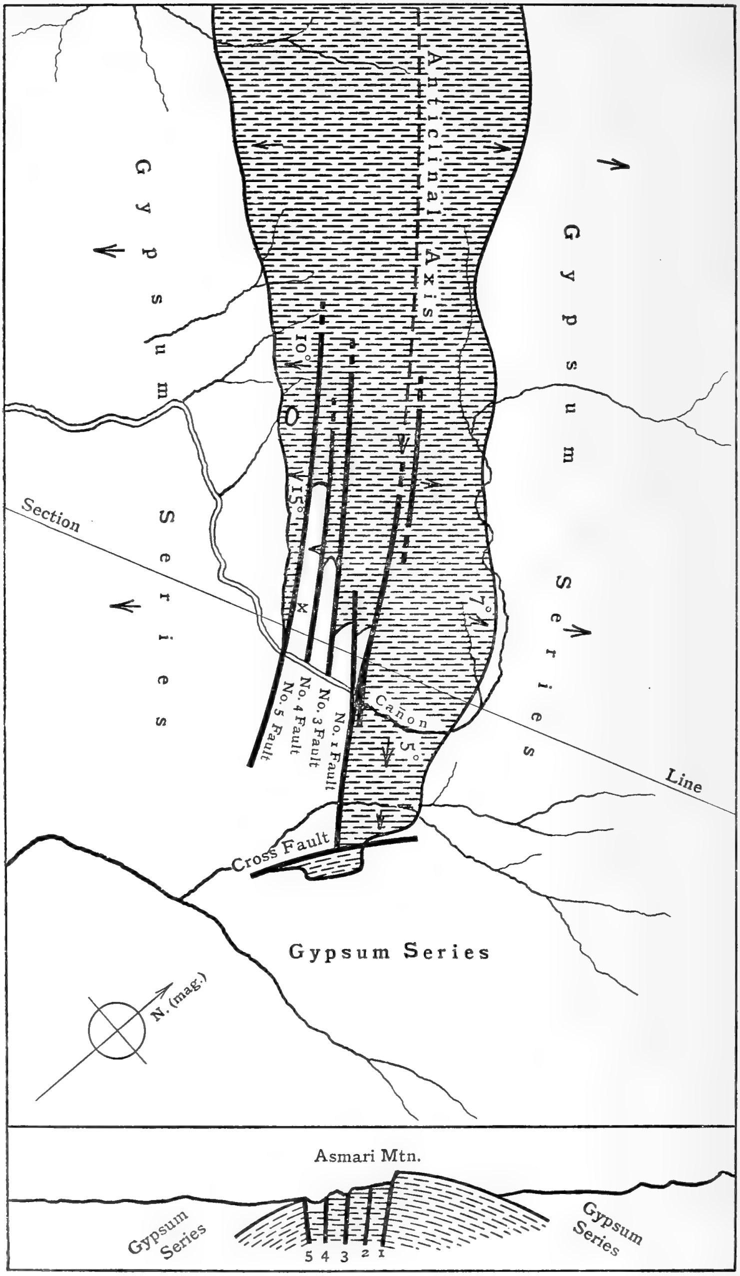
A RIFT-VALLEY so small that its whole extent can be surveyed from the top of one of the bounding walls, so free from soil and vegetation that each fault can be traced by the eye and its hade and displacement measured directly, and so perfectly preserved that the fault-scarps retain the grooves produced by the friction of the sliding rocks, is surely a structure of no little interest. If the valley which I have to describe were in Europe instead of Persia, I do not doubt that it would attract its geological pilgrims and supply illustrations for the text-books for many years to come.

Asmari Mountain, near the oilfields of Maidan-i-Naftun in the Bakhtiari country of Western Persia, is an inlier of Oligocene limestone among the beds of the Fars System (Miocene). The only division of the latter system that comes into the question is the lower or gypsum series, consisting of bedded gypsum with intercalated shales and a few thin limestones. These beds are locally conformable to the Asmari Limestone, although the higher members of the system overlap the lower. The mountain is a 'whaleback,' 16 miles long and 3 wide at the middle, formed by a simple symmetrical anticline plunging at both ends. The north-western end plunges rather steeply, and shows no abnormal structures; but the south-eastern end disappears more gradually, the axis dipping some 5° or 6° only, and here for a distance of 3 miles the fold has collapsed along its length, letting the gypsum-beds down into a trough in the limestone.

This trough is bounded by two main faults hading north-eastwards and south-westwards respectively, with an average hade of 20°, and marked by steep escarpments. The northern scarp, which lies practically along the axis of the anticline, is at one point 500 feet high; but the southern one, being low down on the flank of the anticline, is much less conspicuous. Besides the main faults there are at least three other major faults parallel to them which produce smaller scarps within the valley; the valley-floor thus descends in terraces towards the south-west, besides having a general south-eastward inclination of some 10°. Uphill, towards the crest of the mountain, the downthrow of the bounding faults diminishes gradually to zero, and the valley dies out on the broad top of the anticline. Downhill, towards the plunging nose of the anticline, the trough is closed abruptly by a cross-fault nearly at right angles to the anticlinal axis. The length of the trough is 2½ miles, and its width half a mile.

The downthrow of the most important faults is given below, the

*Map and section, on the scale of 1 inch to the mile (or 1: 63,360), showing the plunging end of the Asmari anticline breaking down into a rift-valley.*



figures being *minimum* estimates of the *maximum* downthrow in each case. The measurements were made by aneroid:—

| | Feet. |
|---|---|
| No. 1 fault (at the mouth of the cañon) ...... | 500 |
| No. 3 fault ........................................ | 200 |
| No. 4 fault ........................................ | >150 |
| No. 5 fault ........................................ | >150 |
| Cross-fault ........................................ | >100 |

In addition to these faults of large displacement, many minor faults of small or insignificant displacement exist in the limestone north of the great escarpment. Some of them can be seen in the walls of the cañon presently to be mentioned, in the development of which they may have played a part.

The photograph (Pl. XII) was taken from a point × on the south-western wall (see map, p. 246), looking northwards across the valley. It shows the escarpments of No. 1 fault (the northern boundary-fault, forming the cliff in the background), No. 3 fault, and No. 4 fault. On the limestone-terrace between the two last-mentioned escarpments there are rounded hillocks of gypsum, and the trough between No. 4 fault and the observer (himself standing on the escarpment of the southern boundary-fault) is entirely filled by the gypsum series.

Although a great deal of the gypsum has been removed in solution, the eastern end of the valley still retains much of its gypsum-filling, which rises in one place nearly to the top of the bounding wall. Pl. XIII shows the gypsum-beds in contact with the limestone-wall, the trace of the fault being clearly discernible. It has already been said that the fault-scarps preserve in their lower portions the smoothed and fluted surfaces produced by the friction of the sliding rocks. This is best shown by the northern boundary-fault at the mouth of the cañon, and is reproduced in Pl. XIV, the man who is seen standing against the cliff-face serving to give the scale.

The drainage of the faulted region is curious in several respects. The only perennial stream that traverses the valley cuts sheer across it from side to side. Rising in the gypsum-beds on the north-eastern flank of the anticline, the stream turns south-westwards and cuts right through the limestone in a deep cañon; the latter breaches the northern fault-scarp where the downthrow is greatest, and from here the bed of the stream lies in the gypsum of the valley-bottom, except for a short stretch between No. 3 and No. 4 faults, where the limestone-floor is again exposed to view. The stream finally breaks through the southern limestone-wall, and so makes its escape from the valley.

In order to understand this curious behaviour, it is necessary to consider the conditions that prevailed before the valley was scooped out. There was then a gypsum cover over the whole area, and the stream in question assumed approximately its present direction at that period. Cutting down through the gypsum cover, it

eventually reached the limestone on the north side of No. 1 fault, while on the south side of this fault it was still in gypsum. Erosion then proceeded more rapidly in the latter part of the stream-course than in the former, with the result that the limestone escarpment began to be laid bare and a waterfall formed where the stream crossed it. But this growing difference in level brought about an increased rate of flow and greater corrosive power above the fall, while at the same time the stream discovered the minor faults in the limestone, and, adapting its course partly to them, cut out in time the present deep zigzag cañon. In the same way, when the gypsum within the valley had been excavated sufficiently, the limestone was again encountered at No. 5 fault; the stream being, however, now confined in a deep channel in the gypsum was not deflected by the obstacle, but was able to saw its way down through it, aided doubtless by the joints in the limestone.

In brief, the river, although younger than the initiation of the faulting, is older than the sculpturing of the inside of the fault-trough, which was largely accomplished by itself and by subsequent tributaries which developed along the main fault-lines of the rift. As regards the limestone arch, the stream is clearly a superimposed one. Nearly all the drainage of the valley falls into this stream, but the eastern end is tapped by another and smaller stream with a precisely similar development.

Other interesting features appear where the cañon opens out in the escarpment of the northern fault. The water falls into a beautiful saucer-shaped pool, which is bounded for two-thirds of its circumference by overhanging walls of limestone. A band of a soft shaly facies of the limestone crops out at the level of the pool, and it has been cut back by the water into a deep recess or gallery as much as 20 feet wide, which encircles the pool on one side. Owing to this process of undercutting, the waterfall is receding in a well-known manner. The water which escapes over the southern lip of the saucer disappears down the fault-plane, and for some distance below the stream-bed is dry. The same curious feature is shown by a smaller wet-weather watercourse that cuts No. 4 fault half-way up the valley.

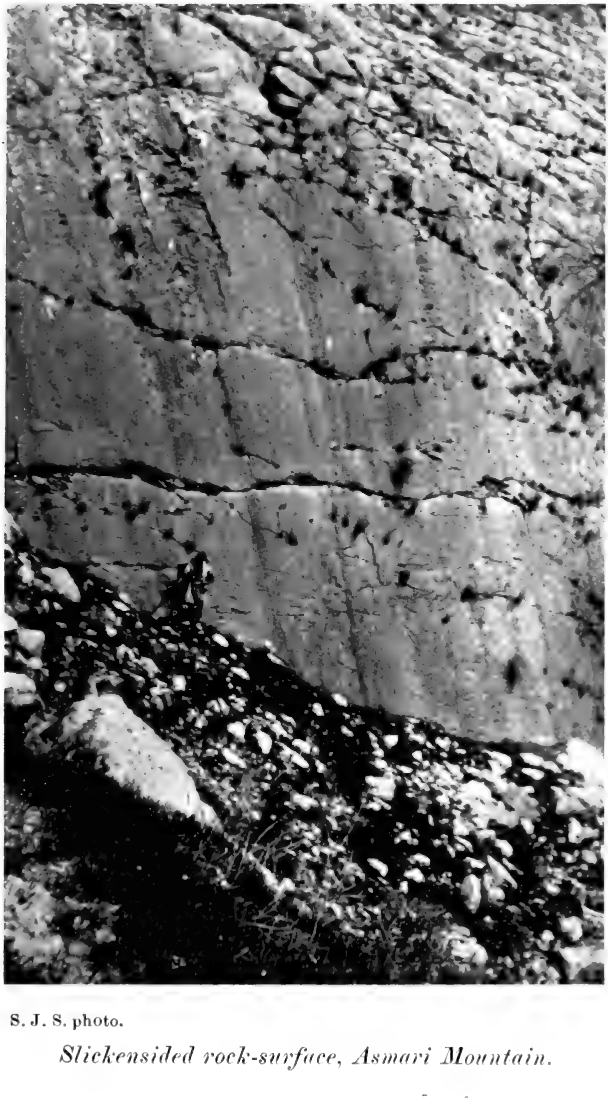
The excellent preservation of the fluted surfaces on the fault-scarps suggests that the last downward movement took place at a very recent date; and, as the whole of this country is much affected by earthquakes, such a conclusion would not seem unreasonable. The evidence of the cañon is against it, however: for the waterfall at its mouth does not now lie on the fault, but has receded some 60 feet from it, while at the point where the stream-bed crosses the fault-plane there is no fall at all. Recent movement along the fault-plane would have produced a fall here, and the time necessary for the obliteration of the fall would, I think, have accomplished the destruction of the engraved face of the escarpment also. For this reason I attribute the preservation of the latter feature simply to the rapid removal by solution of its covering of gypsum.

S. J. S. photo.

*View across the valley, showing the escarpments of No. 1, No. 3, and No. 4 Faults.*

S. J. S. photo.

*Gypsum-beds in contact with the limestone-wall, Asmari Mountain.*



S. J. S. photo.

*Slickensided rock-surface, Asmari Mountain.*

The succession of events here may be summarized as follows:—

(1) Formation of a trough with gypsum-filling by partial collapse of the anticline.
(2) Levelling of the gypsum surface and development of a stream across the position of the buried trough.
(3) The stream, cutting down through gypsum, discovers the faults, etches them out, develops subsequents along them, and thus gradually eats out the gypsum filling the rift, until the present topography results.

For the opportunity to make these observations, as well as for permission to publish them, I am indebted to the Directors of the Anglo-Persian Oil Company, to which I was temporarily attached for duty while serving in the Mesopotamia Expeditionary Force.

## EXPLANATION OF PLATES XII–XIV.

### Plate XII.

View across the valley, showing escarpments of No. 1 fault, No. 3 fault, and No. 4 fault. (See p. 247.)

### Plate XIII.

Gypsum-beds in contact with the limestone-wall. Gypsum on the right, limestone on the left. (See p. 247.)

### Plate XIV.

Slickensided rock-surface. (See p. 247.)

## Discussion.

The President (Mr. G. W. Lamplugh), in asking Mr. Oldham (who had read the paper) to convey the thanks of the Meeting to the Author, commented on the numerous points of interest illustrated by the paper. Not only did it describe an excellent example of trough-faulting, but it showed also how easily fault-features developed by erosion might be mistaken for surface-exhibitions of faulting. We had still to discover what may be the possible limits of surface-displacement by fault-movement. In all the observed cases of recent faulting the displacement at any one time was too slight to affect the general course of the drainage, and this appears to have been the condition in the examples described by the Author, on the presumption that the stream crossed the anticline before the fault-movements had ceased. Physiographical evidence usually indicates that even the biggest faults are of slow growth. The existence of recent fault-scarps of great size is often stated, but the evidence is mostly unconvincing.

Sir Jethro Teall said that he had always thought that the term 'rift-valley' implied a depression directly due to faulting. But the Author had given strong reasons for believing that the valley in question was not a rift-valley in this sense, and, therefore, the term, as used in the title, appeared to be a misnomer.

Prof. W. W. Watts enquired as to the state of mineralization

of the slickensided surfaces. Such surfaces were often siliciform and highly resistant to weathering, on account of their composition and physical state.

Mr. R. D. OLDHAM said that he agreed with the remarks of Sir Jethro Teall regarding the title of the paper. The valley was certainly not a rift-valley in the sense given to the term by its introducer, Prof. J. W. Gregory, but a valley of erosion determined by the letting-down of soft rock into more resistant rock by trough-faulting. The paper gave no indication of the age of the faults, except that they certainly were older than the excavation of the valley; nor was there any note of special mineralization of the slickensided surfaces. The freshness of appearance of those on the scarp-face was attributed to the rapidity of erosion, and in this he considered that the Author had adopted the true explanation. The climatic conditions of the region were peculiar: although arid it was by no means rainless, and at intervals heavy rains occurred, which, aided by the absence of soil and vegetation, gave rise to rapid erosion, while the dryness of the intervening periods checked weathering. Consequently, the effect of stream-erosion in modelling the outward form of the country was more obvious than in countries of greater rainfall.

## POSTSCRIPT TO DISCUSSION.

[If I interpret Prof. Gregory's writings correctly, his intention, in introducing the term 'rift-valley' in 1894, was that it should take the place, in English, of the German term 'Graben'; and it is in this sense that I have used it. But both 'Graben' and the French 'fossé' are defined purely as geological structures, without any reference to physiographic development, and I cannot find any expression of Prof. Gregory's that shows that he intended 'rift-valley' to be used in a more restricted sense. In his 'Geography' he simply states that

'rift-valleys have been formed by earth-movements; they are found where long and comparatively narrow strips of the Earth's crust have sunk beneath parallel fractures.'

Furthermore, all the authors (including Prof. Gregory) who have written of the 'rift-valley of the Rhine' and the 'rift-valley of Central Scotland' have used the term in the same sense as I have, for I believe that it is not maintained that these valleys are simple fault-troughs owing nothing to erosion. I think, then, that my use of the term in question is not contrary to current practice; whether it is contrary to Prof. Gregory's *intention* is another question, and I should be glad to have a ruling from Prof. Gregory in the matter.—*S. J. S.* April, 1920.]

# 13. *The* PETROGRAPHY *of the* MILLSTONE GRIT *of* YORKSHIRE.

By ALBERT GILLIGAN, D.Sc., B.Sc., F.G.S., Lecturer in Economic Geology in the University of Leeds. (Read May 21st, 1919.)

[PLATES XV–XVIII: MICROSCOPE-SECTIONS.]

CONTENTS.



## I. INTRODUCTION.

THE term 'Millstone Grit' is applied to a series of beds which attain a thickness of 5500 feet in Lancashire, consisting of conglomerates, grits, sandstones, and shales with occasional thin impure limestones and beds of chert. It occupies a position in the geological sequence between the Yoredale or Pendleside Group and the Coal Measures. For the purposes of this investigation the base of the Millstone Grit in West and North-West Yorkshire has been taken at the base of the Ingleborough Grit, following the precedent of the Geological Survey as pointed out in the Memoir on the Ingleborough District, 1890, pp. 74–75. Since this is a coarse grit, easily traceable on account of its lithological characters and the bold escarpments to which it gives rise, it forms a good

datum-line. The top of the series has been taken at the top of the Rough Rock, where it can be seen to be overlain by the Lower Coal Measures, as at Whitehall Quarries, Horsforth, near Leeds. However, as no questions of correlation are involved in this work, the exact delimitations of the various beds is a matter of minor importance.

The Millstone Grit Series covers an area in Yorkshire alone of no less than 840 square miles, and is important physiographically, as it forms the capping of most of the hills of the Pennine Chain, such as Mickle Fell, Whernside, Ingleborough, Penygent, etc., and by its presence there preserves the more easily denuded strata below from a more rapid destruction.

Economically the formation is of great importance, being extensively quarried for building purposes in the districts where it occurs, its value for this purpose being well understood by the Saxons and Normans, who used it in the construction of some of their noblest work. As the name implies, a brisk trade was at one time carried on in the making of millstones and grindstones from the grits and sandstones, their use for such purposes dating back to very early times. It also yields an excellent artesian supply of water, many boreholes for public and private works having been made into this rock, and it is for this purpose being more exploited than ever in the neighbourhood of Leeds, Bradford, Huddersfield, and other large Yorkshire towns.

While, however, it has been generally known and valued for the purposes that I have mentioned, it has been undeservedly neglected by geologists as a subject for study from a purely scientific point of view. True it is that much excellent work has been done by Dr. Wheelton Hind, Dr. Wellburn, and others upon the marine fauna of the shales, but much more still remains to be done. The first and, so far as I am aware, the only worker to attack seriously the question of source and origin of the material making up this important series of rocks was the late Dr. Henry Clifton Sorby, who read a paper upon this subject before the Yorkshire Geological & Polytechnic Society at its Annual Meeting in Leeds, March 17th, 1859. Since the publication of that paper, no systematic work has been done along the same lines until the present research was undertaken.

The methods of investigation made use of by Sorby have in a large measure been followed by me; but, in addition to the examination of the coarser material composing the conglomerates and grits, the finer material of the shales and the heavy minerals obtained from the various beds have also been examined. Further, the area laid under contribution for material for this research has been much more extensive than that covered by Sorby. It will, however, be seen that the results of my enquiry corroborate in a remarkable way the conclusions arrived at by that eminent geologist.

## II. Petrography of the Millstone Grit.

As was stated above, the grade of the material making up the beds of this formation varies considerably from a conglomerate with pebbles 2 inches or more in their longer axes to the exceedingly fine material making up the shales. From the coarser beds very large numbers of pebbles have been collected and examined microscopically, while sections of the finer grits and sandstones of different areas have been prepared and, in a few cases, of the shales also. The minerals of the finer-grained beds have also been examined, after suitable preparation by crushing, washing, etc.

### (*a*) Work of Dr. H. C. Sorby.

Dr. Sorby, in the paper already cited, says [1]:—

'By far the commonest pebbles are of quartz like that forming one of the constituents of coarse-grained granites, but a considerable quantity are evidently portions of various yellow, pink, grey, and almost black quartz-rocks or quartz-schists. There are also many pebbles of white or brownish orthoclase-felspar similar to that in coarse-grained granites, and it therefore becomes interesting to ascertain for certain whether some of the quartz and this felspar did not originally constitute a granitic rock. After much careful search, I have at length obtained extremely good proof of this fact, for I have found a few pebbles of undoubted granite, some of which are composed of a union of quartz and felspar like a coarse-grained granite, which are in every respect similar to the quartz and felspar so abundant as pebbles of each mineral alone. Besides such crystalline felspars there occur pebbles of fine-grained felspathic rock with a few laminæ of mica, and though usually much decomposed it appears to have been some kind of eurite. I have also found one pebble of a moderately fine and even-grained rock much like some varieties of greenstone or a fine-grained syenite consisting of a white felspar and of a dark-coloured mineral, both too much decomposed to be accurately identified. It is also interesting on account of being the largest pebble I have yet found, for it is nearly 4 inches in circumference. With the exception of a single pebble of very fine-grained mica-schist, which some would call clay-slate. I have not found good examples of any other decided and well-marked rocks.'

### (*b*) Pebbles of Quartz.

Anyone making a cursory examination of the pebbles of the conglomerate must agree with Sorby that quartz is the dominant type, forming the 'hummer' stones of the quarrymen. They also vary greatly in colour, among the varieties noted by me being black, rose, red, yellow, milky, blue or opalescent, and clear. The varying colours are, of course, due to inclusions of different types. The pebbles may be rounded or angular, but in all cases they show glistening surfaces due to the deposition of secondary silica. One striking fact with regard to their shape is the frequent occurrence of double sphenoid forms. Such forms suggest an origin from a coarse gneiss or pegmatite. The microscope reveals the fact that all these quartz-pebbles have been derived from rocks that have been subjected to mechanical deformation, which in

[1] Proc. Yorks. Geol. & Polytechn. Soc. vol. iii (1859) pp. 673–74.

several cases has been of such an intense character as to produce a beautiful mylonized structure. Undulose extinction is a striking feature, both of the large and of the small quartz-grains. While examining the Kinderscout Grit (this name is merely used as a convenient term for the lower beds) of Burnsall Fell near Bolton Abbey, I found that much of the quartz of the medium-sized pebbles, and most of the quartz of the finer-grained portions, was either blue or opalescent in tint, and this was best seen where the surface had been bleached by a covering of peaty turf, or where the quartz was surrounded by kaolin.

A close examination of the other beds of the series, especially the Rough Rock, show that this blue or opalescent quartz is a common constituent. When examined in thin sections under the microscope, the colour is seen to be due in some cases to streams of minute rounded or irregular particles which are indeterminable; while in other cases, needles of rutile (?) occur in vast numbers, the streams crossing at angles of 60° (see Pl. XV, fig. 2). Liquid inclusions with movable bubbles are common, both in the quartz-pebbles and in the small grains of quartz. The outline is frequently hexagonal or coffin-shaped, and the liquid is usually brown or amber in colour. The types of inclusions will be more fully discussed when dealing with the quartz of the finer material.

## (*c*) Pebbles of Felspar.

These pebbles are exceedingly interesting: they usually, when found in the coarser beds, retain a freshness which is remarkable, the lustre of the cleavage-surfaces being such as might be seen on the freshly-cleaved felspars of an unweathered granite. They vary in colour, but the majority are pink or flesh-coloured. The largest individual pebbles obtained by me have measured about $1 \times \frac{3}{4} \times \frac{3}{4}$ inch, and, curiously, they were embedded in what would be described as fine grit, being quite isolated from other pebbles and perfectly fresh quite to the outside. A considerable number of these have been sliced, and have proved to be invariably microcline or microcline-microperthite. Oligoclase is not at all uncommon in the finer material, while orthoclase is but sparsely distributed, and neither of these has been found as pebbles in any of the beds.

Mr. G. F. Pickering (of Horsforth), whom I have interested in this question, has kindly allowed me to examine a number of sections which he has made of these felspars, and, in all cases, I have found them to be microcline or microcline-microperthite. Another peculiarity of the felspar is the frequent occurrence in it of blebs of quartz (see Pl. XV, fig. 4).

## (*d*) Pebbles of Pegmatite.

Almost as common as the felspars are pebbles of pegmatite, some of these measuring $\frac{1}{2}$ inch cube in the coarser beds. This type was apparently found and described by Sorby, but he gives no account of a microscopical examination of any of the pebbles

which he found, and evidently believed all the large felspars and that associated with the quartz in his 'coarse-grained granite' to have been orthoclase. I have stated above, when describing the felspar-pebbles, that orthoclase is either extremely scarce or absent as large pebbles. Similarly, an examination of these pegmatites in thin sections under the microscope shows that the felspar is, with one exception, microcline or microcline-microperthite. The one exception is, however, of extreme interest. It is the largest piece of pegmatite yet found and was presented to me by Mr. J. Holmes (of Crosshills), to whom I am also greatly indebted for other valuable assistance. Before being broken it measured $5 \times 2\frac{3}{4} \times 2\frac{1}{2}$ inches, and was found in the Middle Grits near Silsden. The felspar in this case is albite, and so the rock would be termed a soda-aplite. The quartz associated with the felspar in these pegmatite pebbles is usually blue or opalescent, and shows undulose extinction, but not the mylonized structure so common in the large quartz-pebbles. Mica (muscovite) is only sparingly present in these pebbles. The pebble which Sorby named a eurite would almost certainly belong to this group.

### (*e*) Pebbles of Igneous Rocks (other than those of the Aplite-Pegmatite Family).

A remarkable assemblage of pebbles consisting of igneous and metamorphic rocks has been obtained from the Middle Grits and Rough Rock of the Aire Valley. Many of these pebbles measured, before being broken for examination, as much as $6 \times 3 \times 1\frac{1}{2}$ inches, while one measured $10 \times 8 \times 4$ inches, and is the largest yet recorded from the Millstone Grit. Occurring as they do in beds which are fine-grained, it is interesting to enquire as to the manner in which they were transported. The bed in which they occur is crowded with plant-remains, and I was told by the workmen that numerous trunks of trees had been unearthed during quarrying operations. This would seem to afford a sufficient explanation, the pebbles having been carried down by drifting vegetation. The remarkable angularity of some of the specimens would also lend support to this theory; but it is not so easy to explain how the plants of the Carboniferous Period such as *Sigillaria*, *Lepidodendron*, etc., with the long horizontal roots, could have obtained so strong a hold upon these large blocks as to transport them for any great distance, such as I conceive these must have travelled. The problem is similar to that of the occurrence of the quartzite and granitic pebbles and boulders found in coal-seams, and I believe that the agency suggested above explains both cases.

The types of igneous rocks represented are the following:—Granites, quartz- and felspar-porphyries (several specimens of each) and quartz-diorite (one specimen).

The granites are always pink or flesh-coloured and fine-grained, no porphyritic crystals having been present in any of them. The usual type is a two-mica granite with orthoclase and plagioclase

felspars, and showing micrographic structure, generally somewhat fine.

The quartz in most cases shows undulose extinction, and the laminæ of the micas and felspars are often curved. A notable feature is the frequent presence of such accessory minerals as zircon and rutile, included often in the quartz and felspar, but usually in greatest quantity in the micas. This last point is of interest, in view of the work which has been carried out by me upon the heavy minerals of the Millstone Grit, and presented in a later part of this paper. Perhaps the most noteworthy of these granite-pebbles is that illustrated in Pl. XVII, fig. 4, which in the hand-specimen shows a distinct gneissose structure; but, when examined in polarized light, it is found to yield no evidence whatever of crushing, and is a particularly fine example of a protoclastic granite or gneiss, the intense foliation having been produced prior to its final consolidation.

The quartz- and felspar-porphyries are usually buff-coloured, with the quartz and felspar (the latter often altered) well seen on the broken surface. The porphyritic crystals are often much corroded, especially the quartz, and the felspars are commonly microcline or microperthite with a tendency to micrographic structure as an outgrowth from some of the felspar-crystals. Liquid inclusions with movable bubbles are abundant in the quartz of a number of these rocks. The ground-mass is of the usual microcrystalline type, in which small wisps of biotite frequently occur. One of these porphyries bore so striking a resemblance to the well-known rhomb-porphyry of the Christiania district that it was sent to Prof. W. C. Brögger for determination. He stated that it was not a true rhomb-porphyry, but said that it was possibly one of its facies, the rock being too much decomposed to make the identification certain.

The quartz-diorite pebble is the only one of basic type yet found.

## (*f*) Pebbles of Metamorphic Rocks.

Sorby records the finding of a single pebble of fine-grained mica-schist or clay-slate, and suggests that their scarcity is accounted for by the ease with which such rocks would be broken up during transport. I can but endorse Sorby's remarks upon the rarity of pebbles of schist through the Grit Series as a whole; I have, however, been fortunate enough to obtain a number of large pebbles of schists and gneisses from the Middle Grits of Silsden. Indeed this has been the 'happy hunting-ground' for the igneous and metamorphic pebbles.

The granitoid gneisses are composed of practically the same minerals as the granites described above, only differing in the structures produced by shearing. In fact, there is a regular gradation quite noticeable when the sections are compared. The schistose rocks form an important group. Generally, they may be described

as mica-schists and quartz-schists. The former show contortions with minute foliations and strain-slip cleavage. Among these pebbles is found one which may provide a clue to some of the problems concerning the source whence the material of the grit was derived (see Pl. XVIII, fig. 2). It has been identified both by Prof. T. G. Bonney and Mr. G. Barrow as coming from the Blair Athol district. Mr. Barrow writes :—

'This is the "Black Schist" associated with the Blair Athol-a-Nain Highland Limestone. Along a great belt of country the lower part of this rock is known as the "Felspar-Rock" of Glen Callater, as that was the place where it was first found. It succeeds a rock especially rich in peculiar forms of chlorite, and there is much of this chlorite still in the lower part of the bed altering to the Felspar-Rock, but less as we ascend. This rock is from the lower part of the "Felspar-Rock"; it contains the felspar (pale-grey under crossed nicols) first determined by Sir Jethro Teall, and in this felspar is the typical dark dust. In addition the pale, almost white chlorite is present in considerable quantity, and the characters of the rock as a whole make it quite unmistakable.'

With this schist must undoubtedly be placed, as allied in origin, some of the others, as they contain the pale chlorite, and present a general family resemblance.

Some of the schists are garnetiferous, and thus help to explain the common occurrence of garnets in the grit-beds; while tourmaline, though not previously discovered in the sections prepared of these rocks, is nevertheless found in considerable quantity in the heavy-mineral separations. Zircons are plentiful, while rutile is also fairly common in some of them.

A few pebbles of slightly-altered sedimentary rocks have also been found.

### (*g*) Pebbles of Sedimentary Rocks.

In the beds of coarse grits at the base and top of the Millstone Grit Series, and in the coarser bands of the Middle Grits, occur numerous pebbles of chert. These are usually black and therefore easily detected, but others are buff, brown, or yellow. Generally, they present the ordinary characters of such rocks when seen under the microscope. Many of these chert-pebbles from the Kinderscout Grit of Upper Wharfedale and Airedale have been sliced and compared with specimens of chert from the Carboniferous Limestone Series; and it has been found that, while organic structures are usually present in those from the Carboniferous Limestone, only a few from the grits show any traces of organisms and then of quite a different nature.

One of the chert-pebbles (see Pl. XVIII, fig. 4) found in the Kinderscout Grit of The Strid, Bolton Abbey, shows beautifully-developed oolitic structure. From the Plumpton Grit at Grimbald's Crag, Knaresborough (exposed in the river-bed), was obtained a very curious grey pebble (see Pl. XVIII, fig. 5), which, in the hand-specimen, shows a number of circular pits suggesting oolitic structure. In many parts the pebble is stained with hæmatite.

Under the microscope the structure is even more remarkable, presenting the appearance of a completely silicified oolite. The concentric structure characteristic of oolites can be traced in many cases. The matrix is cryptocrystalline and microcrystalline silica, and the oolitic grains are irregularly distributed through the rock. No radial structure can be distinguished in any of the oolitic grains. Each of the original oolitic grains is now outlined by a number of small spherical bodies which are each stained with oxide of iron. The diameter of these bodies is, on the average (Pl. XVIII, fig. 5), ·02 to ·03 mm. Similar rounded bodies can be seen scattered through the ground-mass, and showing a tendency to group together by twos and threes. In many of these, when using a high magnification, can be seen a spherical nucleus stained with hæmatite, while the rest of the body is quite clear. The clear part has a somewhat higher refractive index than the silica making up the ground-mass of the rock. The bodies were at first suspected as being of organic origin, but the late Dr. G. J. Hinde, who kindly examined the section for me, failed to identify them as being derived from organisms. In the Geological Survey Memoir on the North-West Highlands of Scotland, is described and figured a pebble from the Torridonian which agrees in a most remarkable way with the one here described.[1] Silicified oolitic Durness Limestone kindly supplied to me by Dr. John Horne, F.R.S., has been examined for comparison, but proved to be quite unlike this specimen, none of the curious spherical bodies being found. The Rough Rock of Whitehall Quarries, Horsforth, has also yielded a pebble with well-developed oolitic structure, so that they have been found in the Lower, Middle, and Upper Grit beds, but they are not of frequent occurrence by any means. Another pebble from the Rough Rock of Horsforth shows traces of organisms when a section is examined by ordinary transmitted light (see Pl. XVIII, fig. 6). They seem to be tubular bodies which have been cut through in different directions. Some of the tubes appear to be quite straight, while others are curved. No structure can be observed even when a 1/9 objective is used. In polarized light almost all trace of the organisms disappears, and the rock looks like a very fine-grained arenaceous mudstone in which somewhat larger angular pieces of quartz are irregularly distributed. Inside these angular pieces of quartz, which is very clear, can be traced the circular sections of the tubular organisms (by transmitted light), and this seems to point to a secondary growth of silica round the organisms.

A black siliceous pebble from the Kinderscout Grit of Embsay Moor shows traces of organisms; these appear to have been brachiopods and sponge-spicules, while a very similar pebble showing organisms was obtained from the grit of The Strid, Bolton Abbey.

[1] 'North-West Highlands of Scotland' Mem. Geol. Surv. 1907, p. 280 & pl. l, fig. 1.

The quarrymen engaged in working the various grits are only too familiar with the frequent occurrence of discoidal masses of shale, which are often in such numbers as to render worthless the large blocks for which the beds are worked. I have examined a great number of these, and have found them to be of ordinary micaceous shale, exactly similar to the shales of Carboniferous age such as the Yoredales or Millstone Grit. In a large specimen found in the Rough Rock at Horsforth, fossil plant-remains have been obtained. These were submitted to Dr. R. Kidston, F.R.S., who pronounces them to be *Cordaites borassifolius*. The origin of these shale-masses is somewhat obscure. Do they represent small mud-puddles infilled at the time of the accumulation of the surrounding coarse material, or are they true pebbles derived from a consolidated shale? The small masses, 1 inch or less in diameter, lie in all directions in the grit; they seem to be transported, and may possibly represent fragments of clay-slate or a similar rock, indeed one such piece has actually been found. The larger pieces lie more or less parallel to the bedding, and seem to be of contemporaneous origin. Furthermore, these latter have the impress of the surrounding grit, while many of the smaller pieces are quite smooth.

## III. Examination of the Finer Material.

The Millstone Grit has been described as an arkose, and no better name could be employed, as it is neither more nor less than a disintegrated granitoid rock which has been reconsolidated.

The rocks which have contributed the material were certainly acid in composition, the quantity of minerals characteristic of basic rocks being of such an order of magnitude as to be quite negligible. A cursory examination of a hand-specimen of the grit shows quartz and felspar, with occasional flakes of mica and often garnet. While, however, mica is not so commonly found in the coarser beds, it is of such abundance in some cases as to make up beds of practically pure micaceous material 2 to 3 feet thick, such as that below the Rough Rock of Keighley Moor; while in the flaggy beds it determines the planes of division.

### (1) Quartz.

The grains vary greatly in the degree of angularity, many being quite rounded in some of the lower beds (those examined from the Kinderscout Beds of Upper Wharfedale show several rounded grains) and also in some of the Middle Grits, such as that of St. Helen's Quarry, Spofforth (Follifoot Grit). In the Rough Rock very few have been found: indeed, they may be described as rare. Much of the angularity is, however, due to a deposit of secondary silica upon the original grain, as is so well seen on the surfaces of the larger pebbles of quartz. It may here be noted that the quartz-grains found in a sandstone near the top of the Carboniferous Limestone at Hoff Beck, Appleby, and quite near

to the outcrop of Millstone Grit of that area, are beautifully rounded, resembling, indeed, in this respect, those of the Penrith Sandstone of the same district. It may, therefore, be that the rounded grains in both the sandstone mentioned above and in the Millstone Grit have been derived from sand-dunes which fringed the coast of the Carboniferous sea, but I am inclined to believe that they were derived from beds of pre-Carboniferous age, for reasons which will be brought forward later.

The grains vary greatly in size, the larger showing the higher degree of rounding, as (of course) is usual. Nothing will be gained by describing in detail the size of the grains; suffice it to say that the larger grains are found in the Kinderscout Grit and Rough Rock, while, as a rule, the Middle Grits are much finer. When examined microscopically, most of the quartz shows (like the larger pebbles) that it has been derived from rocks which have been subjected to mechanical deformation, in that undulose extinction, with crenulate and mylonized structure, is common. The larger grains show these features better than the smaller. The following percentages have been obtained, by taking typical sections of the grit of varying degrees of coarseness:—

| | | | | | *Per cent.* |
|---|---|---|---|---|---|
| Coarse beds: | Grains showing signs of pressure | | | | 84 |
| Medium beds: | Do. | do. | do. | do. | 62 |
| Fine beds: | Do. | do. | do. | do. | 45 |

The reasonable deduction is that most of the quartz was derived from such rocks as granitoid gneisses and schists.

## Inclusions in the Quartz-Grains.

It may be stated, first of all, that no single grain of quartz entirely free of inclusions has been detected in any of the sections of the grit examined: it being most usual, indeed, to find them crowded with inclusions. The inclusions are of many different kinds, and comprise the following:—

(*a*) minerals showing good crystal form; (*b*) acicular crystals possibly of rutile; (*c*) glass, gas, and fluid cavities; and (*d*) black dust quite indeterminable, and occurring both irregularly and in rows and streams.

The researches of Dr. W. Mackie on the quartz of granites, gneisses, and schists of Scotland have shown that the type of rock from which the grains have been derived may be deduced from an examination of these inclusions.[1] He has classified the inclusions as follows:—

I. Regular (these would include those under (*a*) above).
II. Acicular ( Do. do. do. do. do. (*b*) do. ).
III. Irregular ( Do. do. do. do. do. (*c*) and some (*d*) above).
IV. Negative (that is, without inclusions, or where inclusions of the irregular type are so small as practically to escape notice).

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[1] Trans. Edin. Geol. Soc. vol. vii (1897) pp. 148–72.

Further, Dr. Mackie remarks:

'It may be stated as a fairly general law that acicular and irregular inclusions pre-eminently abound in the quartz of granite; that the regular group is to be found in various proportions, but always in relatively large numbers, in the quartz of gneiss and the younger schistose rocks.'

He also states that, in his work on the Scottish rocks, inclusions of different kinds occur frequently in one and the same grain, and then such a grain is classed under the heading of 'acicular' or 'regular' if these forms are present at all.

Among the minerals of good crystal form included in the quartz of the Millstone Grit, and termed 'regular' inclusions, are the following (in decreasing order of relative abundance):—zircon, tourmaline, rutile, and oxides of iron.

The acicular inclusions appear to be almost invariably rutile, though tourmaline and sheaf-like aggregates, which may be sillimanite, have been rarely seen.

In their order of relative abundance, the inclusions may be classed as follows:—regular, irregular, acicular, negative. (These last are almost negligible).

It follows from Dr. Mackie's determinations that the deduction from the inclusions is in agreement with that previously made: namely, that the quartz has been derived for the greater part from rocks which have been subjected to pressure. Again, the frequent occurrence of streams and rows of the irregular inclusions is a feature which reminds one of the inclusions in such a rock as the Lewisian Gneiss, of which I have had sections prepared for comparison.

Sir Jethro Teall states, regarding the inclusions in the blue quartz of the pyroxene-gneisses with quartz of the North-West Highlands,[1]

'These are of four types: (1) rows of minute dots; (2) extremely thin hairs, formed in all probability of the same substance as the dots; (3) cavities with very dark borders; and (4) minute irregular flecks and grains. . . . . A similar blue quartz occurs in the grits of the Southern Highlands, and there also it contains the minute hairs and rows of dots . . . . . . . . . it seems probable that this colour is due to the inclusions.'

All the types mentioned by Sir Jethro Teall are present in the quartz of the Millstone Grit; and further, as was stated previously in the description of the larger quartz-pebbles, liquid inclusions, usually hexagonal or coffin-shaped and with movable bubbles, are common. The relative size of the bubble to the fluid-cavity differs greatly in the various grains, which points to the fact, as Sorby has shown, that they have been derived from rocks which have solidified at different temperatures and pressures, the ratio of bubble to cavity being of course greatest in those which have solidified at the greatest depths, and therefore probably from the highest temperature. The highest ratio of bubble to cavity is about 0·25,

[1] 'North-West Highlands of Scotland' Mem. Geol. Surv. 1907, p. 54.

while the lowest is about 0·075. It is of interest and importance to note that liquid cavities with movable bubbles occur in the quartz of the granite, gneiss, and quartz-porphyry pebbles described in an earlier part of this paper.

## (2) Felspar.

The grains of felspar are commonly well rounded, as is usually the case in sedimentary rocks, and often somewhat elongated, this form having been determined by cleavage. As with the larger pebbles, the dominant felspar in the finer material is microcline, next in order comes microcline-microperthite, then oligoclase, and orthoclase. Very basic felspars appear to be altogether absent in the fresh state, and were never, I believe, present in any notable quantity. These felspars are often exceedingly fresh. As in the larger pebbles, the cross-hatching of the microcline is wonderfully well shown, while the oligoclase is frequently quite unaltered (Pl. XVI, fig. 1).

Microcline is, as is well known, the most resistant of the felspars to alteration, and is found quite fresh in deposits of all ages. The oligoclase and orthoclase are, however, much more readily decomposed, and their freshness here has a deep significance, which will be emphasized and discussed when the mode of derivation and accumulation of the material comes under consideration.

It appears probable, from the frequent association of calcite with decomposed felspar, that the original form of the felspar had been one of the less basic soda-lime group. This was especially well seen by me in some sections of the grit from a borehole at Meanwood, Leeds.

An investigation into the question of the original freshness of the felspar and its alteration by subsequent atmospheric action was made by means of sections cut of the grit from a deep boring at Bradford, and it was found that, as a general statement, it may be asserted that the percentage of fresh felspar increased with the depth from which it was obtained. In this connexion a further confirmation is to hand in the fact that it sometimes happens that a borehole put down in the grit for water fails to tap the supply, since the density of the rock approaches that of a true granite, and hence its porosity is very low. The rock has to be blasted at the bottom of the borehole, so as to open up a connexion with a joint through which the water may find its way to the borehole.

### Inclusions in the Felspars.

Quartz-blebs are very common in the microcline, while zircon, tourmaline, and rutile also occur, but of these zircon is by far the commonest. Muscovite, as a primary inclusion and not due to decomposition, is also fairly common.

### (3) Mica.

In the coarse grit-beds mica is not plentiful, but becomes an increasingly important constituent as the fineness of grain of the rock increases, until in the shales it becomes the dominant mineral. The potash-micas are the most plentiful in the flags and sandstones, while the ferromagnesian micas are much more common in the shales. It may be that much of the mica in the shales is of secondary origin, as suggested by Mr. W. M. Hutchings for the mica in the shales of the Coal Measures.[1]

The size of the mica-flakes is important, ranging up to a quarter of an inch in diameter in some of the very micaceous beds, such as that on Keighley Moor; while similar large micas were observed in the shales obtained from deep boreholes at Leeds and Bradford.

### Inclusions in the Micas.

These are very frequent in the ferromagnesian type, and, in addition to the oxides of iron which occur along the cleavage-planes, zircons are extremely common. These are surrounded by the usual pleochroic haloes. It seems quite clear that the excellence of the crystalline form of the zircons obtained from the shales and grits can best be explained by supposing them to have been carried along as inclusions in the micas, and only released by the decomposition of the mica in the place where they are now found.

## IV. Heavy Minerals of the Millstone Grit.

From the commencement of my investigations I have been able to identify many of the so-called 'heavy minerals' in the ordinary sections of the grit which I have had prepared, and this is notably the case with the zircons, garnets, and tourmaline; but, for the more detailed examination of such minerals, recourse was had to the following method of separation. The grit, sandstone, or shale-specimen, weighing approximately 1000 grms., was pounded, but not ground, in a mortar, and, when thus prepared, was placed upon the coarsest of a series of sieves of 10, 30, 60, and 90 mesh to the inch respectively, and very thoroughly shaken. It was found that almost the whole of the heavy minerals were passed by the 90 mesh, this being especially true of the zircons, rutile, and monazite. From some of the beds, garnets large enough to be retained above the 60 mesh were numerous; but, of course, this was known by examination of the specimens with a hand-lens. After dealing with some twenty specimens by separating the heavy minerals from all the grades which passed the 10-mesh sieve, I found that it was sufficient to examine the material in the following way:—

Shales—material which passed the 90 mesh.
Sandstones— Do. do. do. do. 60 and 90 mesh.
Coarse grit— Do. do. do. do. 30, 60, and 90 mesh.

[1] Geol. Mag. 1890, pp. 263–316, & *ibid.* 1894, pp. 36–45.

The finer material or dust, caused by the pounding, and still adhering to the grains, or present in large proportion in that which had passed the 90 mesh, was removed by washing and decantation. When it was deemed necessary, the material after washing was treated with dilute hydrochloric acid to remove the iron oxides. After washing and drying, some were mounted for examination with the microscope in order that the character of the grains and the relative abundance of the heavy minerals might be noted. The separation was carried out with a Sollas bottle and Thoulet's Solution of specific gravity 2·8.

HEAVY MINERALS PRESENT.

| Cubic System. | Tetragonal. |
|---|---|
| Garnet. | Anatase. |
| Iron Pyrites. | Rutile. |
| Magnetite. | Zircon. |
| | Xenotime. |
| **Hexagonal-Rhombohedral.** | **Orthorhombic.** |
| Calcite. | Andalusite. |
| Ilmenite. | Barytes. |
| Tourmaline. | Brookite. |
| | Topaz. |
| **Monoclinic.** | **Triclinic.** |
| Monazite. | None. |

In addition to these, the following minerals were present in practically all the separations:—Leucoxene—as an alteration-product of ilmenite; small rounded grains of limonite and clay-ironstone. Pyrolusite is often present as a cement in some of the coarser beds, and the presence of manganese was proved in many cases by chemical tests.

## Description of the Heavy Minerals.

Garnets.—These are by far the most abundant of the heavy minerals in the coarser beds of the Kinderscout Grit and Rough Rock. Some garnetiferous layers were found in the Rough Rock of Cragg Hill Quarry, Horsforth, in which they occurred in such quantity as to form the dominant mineral species. They are very variable in size, the largest grains measuring as much as 1·0 to 1·5 mm. in diameter. They are generally of a rich pink colour, but many of a deep wine-red colour also occur.

In the garnetiferous layers they show evidence of having undergone alteration to some chloritoid substance by which they are surrounded in pits, and the whole surface of the layer is deeply stained with oxide of iron. Indeed, this characteristic pitted appearance and colour of these layers has enabled me to collect specimens from the heaps of broken rubble in the quarries. Where the garnets are in contact with the large pebbles of quartz, the quartz itself is pitted, which is due doubtless to some chemical interaction between the garnet and the quartz.

Under the microscope the larger grains are seen to be fairly rounded, but the smaller ones are angular, this being due to the extraordinary development of the dodecahedral cleavage (best seen in the small garnets which occur in the shales of the Grit Series, and it is also the characteristic feature of the garnets that I have separated from the sandstones of the Coal Measures). Dr. T. O. Bosworth[1] has noted a similar peculiar angularity in the garnets found in the Coal-Measure sandstones in Scotland, and the figures given by him could well be taken to represent the garnet-grains of the Millstone Grit and Coal-Measure sandstones of Yorkshire.

Another remarkable feature is the skeletal or drusy development shown by a very large proportion of the larger grains, the rhombic faces of the small individuals that make up the grains being easily observable. Deep pits with apparently rhombic section also occur in the grains, though perforations are somewhat rare.

Inclusions are very common in the larger grains, so much so that the grains are seldom isotropic. The nature of these inclusions has not been determined with certainty, but most of them are of some mineral with strong double refraction, occurring either as stumpy prisms, or long slender needles; while others, again, are of irregular outline.

Chemical and spectroscopic tests show that the garnets are chiefly of the almandine type.

Iron Pyrites.—This mineral is not nearly so abundant in the Millstone Grit as in the Coal Measures. It occurs generally as small cubes or rounded grains.

Magnetite.—In none of the separations is this mineral abundant. It is mostly in the form of rounded grains, but some of octahedral form have been found. As one would expect, it is most abundant where ilmenite is also common.

Anatase.—As separate grains which may be of primary origin, this mineral is rare; but, as a secondary outgrowth from leucoxene, it is abundant. The stages can be traced as follows:—ilmenite, leucoxene, anatase, or rutile. It is colourless, and of tabular habit, with low pyramids developed in some cases.

Rutile.—In some separations this mineral is very abundant, indeed, it is the most abundant heavy mineral in some of the shales. It has proved to be invariably present. The colour varies from light yellow, through deep amber and brown, to foxy red. It may be said that the deep amber and brown are the most abundant. Many crystals show an almost complete development of the faces with sharp edges. In other cases the prism-faces only are well developed, and the terminations irregular or rounded.

[1] 'The Heavy Minerals in the Sandstones of the Scottish Carboniferous Rocks' Proc. Geol. Assoc. vol. xxiv (1912) pp. 57–61 & pls. x–xi.

Geniculate or cordate twins are extremely rare, and only a few cases of polysynthetic twins have been noted.

Colourless rutile after leucoxene has been noted in many cases.

Zircon is present in every bed that has been examined, but is by far the most abundant in the micaceous and arenaceous shales, fine-grained grits, sandstones, and flags. Of the true grit-beds it is of most frequent occurrence in the beds comprising the Middle Grits, notably in the grit of Addingham Edge and the associated beds. While well-developed crystals are found in all the beds, the highest proportion is in the micaceous beds, and here the sharpness of outline is most striking. It would suggest, as mentioned above, that they have been transported to their present position enclosed in some mineral, possibly a ferriferous mica which has decomposed and released the zircon. There is confirmation of this hypothesis in the fact that, in several sections of the grits, biotite is found enclosing zircon. The crystals vary much in habit, the ratios of length to breadth varying from 2 : 1 to 6 : 1, the greatest proportion being about midway between these limits.

Lengths measured on good crystals:—·09, ·18, ·25, ·30, ·35 mm.

FORMS OBSERVED.

Prisms 100 with pyramids 111.
Prisms 100 and 110 with pyramids 311 and 111.
Prisms 100 and 110 with pyramids 111.
Prisms 100 with pyramids 111 and basal plane 001.

These last are somewhat rare.

The terminations in many cases are rounded, owing to the development of a large number of pyramid faces.

No capped crystals have been found, although a very careful look-out has been kept for them

One twinned crystal similar to that figured by Mr. R. H. Rastall & Mr. W. H. Wilcockson from the microgranite of Threlkeld Quarry, near Keswick,[1] has been found.

Zonary structure is common, though it does not seem to be characteristic of any particular habit. The zoning is more common in the central part of the crystals than in the outer portions.

Inclusions are numerous, and consist of the following types:—

(1) gas and glass inclusions of various forms, a tubular form being common; (2) other minerals, usually with regular outline, and including zircon (xenotime) and possibly apatite; (3) negative crystals.

It has very frequently been observed, when using a high magnification, that the inclusions themselves contain inclusions, especially those of tubular form. The inclusions are, in some cases, zonally arranged, and lie with their long axes parallel to the faces of the crystal. It is impossible to photograph these inclusions so as to show their abundance in any single case, as they, of course, do

[1] Q. J. G. S. vol. lxxi (1915–17) p. 612.

not lie in the same plane, and hence it requires a careful search by racking the microscope up and down for each crystal to examine them adequately.

The zircons are for the most part water-clear, though some are cloudy. Associated with the zircons, as regards form and optical properties, are some reddish and reddish-brown crystals which are possibly xenotime. These are often clouded with alteration-products.

Calcite.—In some of the separations made from the Rough Rock derived from a borehole at Meanwood, Leeds, considerable quantities of calcite were obtained by using liquid of sp. gr. 2·7. In the microscopic sections of the same beds the calcite was seen to form the matrix in a large part of the section. It is worthy of note that the calcite was found to be most abundant, as one would naturally expect, in proximity to shales yielding a marine fauna. It cannot be said that calcite commonly acts as a matrix to the grit; and it has not been found in any quantity, except under the conditions mentioned above.

Ilmenite.—Of the iron-bearing minerals this is by far the commonest, if we exclude the limonite which is so abundant as a matrix and the grains of clay-ironstone. In nearly all cases it forms the core of an aggregate of leucoxene, anatase, and rutile crystals, to which it has given rise.

Tourmaline.—This mineral is of very common occurrence throughout the Millstone Grit Series. Good crystal outline has frequently been observed, and is in all cases that of the prism terminated by rhombohedra. The grains have often been so worn as to be almost spherical. The colour is very variable, but some shade of brown is the dominant one. Blue tourmaline is frequently present; the colour, however, is seldom very intense. The pleochroism of the brown variety is strong, while that of the blue is much weaker.

Inclusions are not common, but (when present) are small and indeterminable.

Barytes.—Like the calcite this acts as the matrix in many cases, and has only been separated in any quantity from the grit of one locality, namely, Great Almscliffe Crags (Kinderscout Grit) of Wharfedale.

Brookite.—Only one undoubted grain of this mineral has been found. It has a pale-yellow colour, and the pleochroism is weak. The striations parallel to the vertical axis are well developed.

Monazite.—Of all the heavy minerals this is certainly the most important and interesting. Its presence had long been suspected in the separations from the Rough Rock; but, when the garnetiferous layers were found and separations made, the honey-yellow grains of monazite were so plentiful that its identity could be

established beyond doubt. For this purpose, both chemical and spectroscopic tests were made. The grains are generally rounded, though a few of fairly-good crystal outline occur. Often it is clouded with brownish alteration-products.

Its presence has now been determined in many of the beds of the series from the Kinderscout Grit to the Rough Rock. Nowhere, however, has it been found in such abundance as in the garnetiferous layers of the Rough Rock at Cragg Hill Quarry, Horsforth.

I think it desirable here to point out that I have paid visits to the Cragg-Hill and Whitehall Quarries, Horsforth, much more frequently than to any other locality, on account of their proximity to my home; also that, by having them under such close observation, I have been enabled to discover here the garnetiferous layers: they may occur in just as great abundance elsewhere. I am convinced, therefore, that exact statements regarding the abundance or otherwise of minerals in sedimentary deposits must be made and received with caution, unless such statements refer to a succession of beds in a quarry-face, section, or borehole, or where horizons can be definitely correlated. For example, these garnetiferous layers which have yielded such an abundance of heavy minerals are from a quarter to half an inch thick, and, unless a careful watch had been kept upon the material that was being quarried and worked, I make bold to say that they would never have been found. At the present time, when the Cragg-Hill Quarry is not being worked, it is absolutely certain that no one could discover these layers on the quarry-face, and an average specimen of the grit would yield a totally erroneous result regarding the amount of heavy minerals, as I have computed that a garnetiferous layer is about 500 times as rich in heavy minerals as the normal grit.

It seems to be better for the present purpose to state the results, not in order of abundance only, but in a more general way with regard to the minerals present:—

(1) in the different lithological types of beds examined;
(2) in the succession of beds examined;
(3) in separations from various localities.

(1) The different lithological types of beds may be arranged as follows:—

(*a*) Coarse grits and conglomerates containing pebbles half an inch or more in diameter: these yield chiefly—garnets, ilmenite and leucoxene, tourmaline, monazite, magnetite.

(*b*) Grits containing no pebbles more than half an inch in diameter: these yield—garnets. ilmenite and leucoxene, tourmaline, monazite, rutile, magnetite.

(*c*) Grits containing no particles more than a quarter of an inch in diameter: these yield—garnets, ilmenite and leucoxene, tourmaline, monazite, rutile, zircon, magnetite.

(*d*) Sandstones, with grains about an eighth of an inch and less in diameter: these yield—garnets, zircons, rutile, tourmaline, monazite, ilmenite and leucoxene, magnetite.

(*e*) Shales (arenaceous): these yield—zircons, garnets, rutile, tourmaline, leucoxene.

(*f*) Shales (micaceous): these yield—zircons, rutile, garnets, tourmaline, leucoxene.

The position in the list of minerals gives an indication of the relative abundance, the first-named being most plentiful.

It will be seen from this that the finer-grained the beds are, the more important become zircon and rutile.

(2) Succession of beds examined.—For the purpose of this synopsis it will be unadvisable to enumerate every bed, as the localities are given in the table (p. 270), but I simply divide the series into Lower, Middle, and Upper: the Lower to include all beds below the Leathley Sandstone of the 1-inch Geological Survey Map, Sheet 92 (Skipton), to the top of the Yoredale Shales and Limestones of Ingleborough, Penygent, Fountains Fell, etc.; the Middle division includes all beds from the Leathley Sandstone to, but not including, the Flags at the base of the Rough Rock, as shown on the map mentioned above; and the remaining Upper division all beds up to the Lower Coal Measures seen resting upon the Rough Rock at Whitehall Quarries, Butcher Hill, Horsforth.

(*a*) Lower Division.—Coarse beds (all conglomerates, grits, sandstones) contain garnets, ilmenite and leucoxene, zircon, tourmaline, rutile, monazite, magnetite. Fine beds (shales) contain zircons, rutile, garnets, tourmaline.

(*b*) Middle Division.—Coarse beds (grits and sandstones) contain zircons, rutile, garnets, tourmaline, ilmenite and leucoxene, magnetite, monazite. Fine beds (shales) contain zircons, rutile, tourmaline, garnets. It must be stated here that in some of the separations made from the shales of Otley Chevin almost pure cultures of zircon were obtained, only a few grains and particles of rutile and tourmaline being present.

(*c*) Upper Division.—Coarse beds (grits and conglomerates) contain garnets, ilmenite and leucoxene, zircon, rutile, tourmaline, monazite, magnetite. Flags at the base of the Rough Rock contain zircons, rutile, garnets, tourmaline.

The striking fact which appears evident from this enumeration is that the heavy-mineral contents of the Lower and Upper divisions, so far as the coarse beds are concerned, are similar; while, in the Middle division, the garnets, which are the dominant mineral species in the other two, become subordinate to zircon and rutile.

The fine beds all through show very little differences, zircons being the most plentiful in them all.

Only two beds of shale of marine origin and yielding marine fossils have been examined. These were of the usual intense black, and exceedingly fine-grained. The only heavy minerals found were rhombohedral carbonates (presumed to be calcite), one or two grains of sulphide of iron, and one very small zircon.

It becomes quite clear from the results recorded above that the evidence yielded by the investigation of the included pebbles and the coarser material is borne out in an interesting manner by the presence of such heavy minerals as those described.

HEAVY MINERALS OF THE MILLSTONE GRIT.

| | Garnet. | Iron Pyrites. | Magnetite. | Anatase. | Rutile. | Zircon. | Xenotime. | Calcite. | Ilmenite and Leucoxene. | Tourmaline (Blue). | Tourmaline (Brown). | Cordierite. | Barytes. | Brookite. | Topaz. | Monazite. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rough Rock, Cragg Hill Quarry, Horsforth | × | ... | × | × | × | × | ... | ... | × | × | × | ... | ... | ... | ... | × | Rough Rock. |
| Do. do. Do. do. Do. (garnetiferous layers) | × | ... | × | × | × | × | × | ... | × | × | × | ... | ... | ... | ... | × | |
| Do. do. Whitehall Quarry, Butcher Hill, Horsforth | × | ... | × | × | × | × | ... | ... | × | ... | × | ... | × | ... | ... | × | |
| Do. do. Hawkesworth Wood Quarry, Horsforth | × | ... | ... | × | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Do. do. Clayton Wood Quarry, Horsforth | × | ... | × | × | × | × | ... | ... | × | ... | × | ... | × | ... | ... | × | |
| Do. do. Bramley Fall Quarry, Newlay | × | ... | ... | × | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Do. do. Bore-hole at Tannery, Meanwood, Leeds | × | × | ... | × | × | × | ... | × | × | ... | × | ... | ... | ... | ... | × | |
| Do. do. Rumbles Moor (above Ilkley) | × | ... | ... | × | × | × | × | ... | × | ... | × | ... | ... | ... | ... | × | |
| Do. do. Keighley Moor | × | ... | ... | ... | × | × | ... | ... | × | × | × | ... | ... | ... | ... | × | |
| Do. do. Do. do. Micaceous bed | × | ... | ... | ... | × | × | × | ... | × | × | × | ... | ... | ... | ... | × | |
| Flags below Rough Rock, Butcher Hill, Horsforth | × | × | ... | ... | × | × | ... | ... | × | × | × | ... | ... | ... | ... | × | Middle Grits. |
| Earl's Crag, Silsden | × | ... | ... | ... | × | × | × | ... | × | × | × | ... | ... | × | ... | × | |
| Netherwood Plantation Quarry, Silsden | × | ... | × | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Steeton Moor | × | ... | × | ... | × | × | × | ... | × | ... | × | ... | ... | ... | ... | × | |
| Otley Chevin ('Driwhyte' of Mr. Nunn's Quarry) | × | × | ... | ... | × | × | ... | ... | × | × | × | ... | ... | ... | ... | ... | |
| Do. do. (shale associated with 'Driwhyte' Grit) | × | × | ... | ... | × | × | × | ... | × | × | × | ... | ... | ... | ... | ... | |
| Snosty Quarry, Bardsey (grit) | × | × | ... | ... | × | × | × | ... | × | × | × | ... | ... | ... | ... | × | |
| Do. do. Do. (shale) | × | × | ... | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Harewood Grit, East Keswick, Bardsey | × | ... | ... | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Shale above Harewood Grit, East Keswick, Bardsey | × | × | ... | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Follifoot Grit. river-bed, Grimbald's Crag, Knaresborough | × | ... | ... | × | × | × | × | ... | × | × | × | ... | × | ... | ... | × | |
| Do. do. Plumpton Rocks, near Knaresborough | × | ... | ... | × | × | × | × | ... | × | ... | × | ... | × | ... | ... | × | |
| Weston Grit, Otley | × | ... | × | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | × | × | Kinderscout Grit. |
| Great Almescliffe Crags, near Weeton, Wharfedale | × | ... | ... | ... | × | × | ... | ... | × | × | × | ... | × | ... | ... | × | |
| 'The Strid,' Bolton Woods, Wharfedale | × | ... | ... | ... | × | × | ... | ... | × | ... | × | ×? | ... | ... | ... | × | |
| 'Bearing Grit,' Grassington Moor | × | ... | × | ... | × | × | ... | ... | × | ... | × | ... | × | ... | ... | × | |
| Bowland Knotts, near Slaidburn | × | ... | ... | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Ingleborough (Coarse bed at the base of the Millstone Grit) | × | ... | ... | × | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Penygent ( Do. do. do. do. ) | × | ... | × | × | × | × | ... | ... | × | × | × | ... | ... | ... | ... | × | |
| Great Whernside ( Do. do. do. do. ), Kettlewell | × | ... | × | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Old Cote Moor ( Do. do. do. do. ), Arncliffe | × | ... | × | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |
| Fountains Fell ( Do. do. do. do. ) | × | ... | × | ... | × | × | ... | ... | × | ... | × | ... | ... | ... | ... | × | |

The heavy minerals may be classified, according to the type of rock which is likely to have yielded them, as follows :—

Garnets—crystalline schists, gneisses, granulites, and granites.
Magnetite—crystalline schists, gneiss, and many igneous rocks.
Rutile—granite, crystalline schists.
Zircon—crystalline schists, gneisses, syenites, acid eruptive rocks.
Xenotime—granites and gneisses.
Tourmaline—granites and pegmatites, and, as shown later, schists.
Topaz—granites.
Monazite—granites.
Cordierite—crystalline schists (since, however, this is so rare a mineral in the grits, the evidence is of little importance).
Ilmenite and its derivative leucoxene—scattered through igneous rocks, usually of basic type.
Anatase—This is, I believe, mostly of secondary origin, as stated above.
Brookite—granites and crystalline schists.
Iron pyrites—this is chiefly of secondary origin in the grits.

The most interesting of these minerals is undoubtedly the monazite, which, as shown in the lists, is present in almost all the beds examined, but chiefly in the coarser type, and most of all in the Rough Rock. When it was first determined to be monazite (February 1917)[1] the only other records for the British Isles, so far as I am aware, were those made by Sir Henry A. Miers for Cornwall and by Sir Jethro Teall for Loch Dee Granite.[2] It seemed to me, therefore, that here might be a crucial test for the theory of its derivation from a northerly source, and I find that Dr. W. Mackie has obtained this mineral in a large number of separations from granites of Northern Scotland. I have also, through his kindness, had the opportunity of examining a remarkable series of his slides showing the monazite and other minerals which he has so obtained. Dr. W. Mackie has given me his permission to quote his remarks, and they are here appended :—

'I have not so far published anything regarding monazite in the rocks of the North of Scotland, but I have quite a number of observations regarding that mineral which have been accumulating for the last couple of years or more. I find it unexpectedly widely distributed in the granites of the North of Scotland; thus, out of 32 specimens of granite examined in this connexion, I find that monazite is present in 25, xenotime in 23, both minerals being found together in 18. It is relatively abundant in the younger granites, *e. g.* in the red granites of Elginshire, while I have found it in some of the Shetland granites, *e. g.* that of Nesting. It is also present in the Central Grampian granite, though not so abundantly in the specimens that I have hitherto examined; but perhaps the richest example that I have so far seen was in a sample from a xenolithic (probably older) granite included in the Central Grampian granite, which I took many years ago from the summit of Cairngorm. I find it in the grey granite of Aberdeen (Rubislaw), which is presumably one of the older granites. It occurs in many granites in well-defined crystals, in others in rounded or ovoid grains with rather corroded-looking surfaces. . . . In clastic rocks, *e. g.* in our local Upper Old Red Sandstones, I have found monazite, but so far not abundantly.'

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[1] I am indebted to Prof. H. L. Bowman for his kindness in making confirmatory spectroscopic tests of this mineral.

[2] 'Silurian Rocks of Britain, vol. i—Scotland' Mem. Geol. Surv. 1899, p. 619.

At a later date he writes:—

'Since I wrote to you about monazite I have looked into the matter a little farther, and have now made separations from 52 granites and have recorded the presence of monazite in 43—a very high proportion, as you see. It is less frequently present in the hornblende and sphene-bearing granites than in the simple biotite-granites or the muscovite-biotite granites; though it is not absolutely absent from the sphene-granites, it is certainly much rarer in these.'

I have practically nothing to add to these remarks of Dr. Mackie, except to point out that the granites which he found richest in monazite are precisely the types found in the Millstone Grit. Sphene I have not so far recorded: consequently, it would appear that sphene-bearing granites were not abundant in the area from which the material came.

## V. Heavy Minerals in Pebbles found in the Millstone Grit.

Some of the pebbles of granite and schist were large enough to enable me to use a small portion for the separation of the heavy minerals without destroying the whole pebble, which would be most undesirable. The portion which was available for such work was, however, too small to yield results that may be regarded as satisfactory, and the list is only given for what it is worth.

Perhaps the most remarkable result yielded by this part of the work is the abundance of rutile, zircon, and tourmaline in all the pebbles, whether granites or schists. Indeed, it will be seen that tourmaline is most abundant in the schists. Monazite is of somewhat rare occurrence, but that it should be found at all is a remarkable fact. Apatite is also recorded from three of the granites, while so far it has not been detected in any of the separations from the grit. This mineral is generally regarded as less liable to alteration than monazite, and is of common occurrence in sedimentary deposits generally, so that its absence from the grit is all the more remarkable. It must be noted, however, that apatite-needles have occasionally been observed in the quartz of the grit.

### Description of Minerals.

Garnets.—These frequently show good crystal outline, but are more usually in a fragmentary condition. In a few cases they show the dodecahedral cleavage, and also contain inclusions; but all features due to alteration are, of course, absent.

Iron Pyrites.—This only occurs in one of the schists, and is in the cubical form, often as aggregates of small cubes.

Magnetite.—This mineral is also of rare occurrence, and does not show good crystal outline.

Anatase.—As in the case of the anatase in the grit, it is present most commonly as a derivative from leucoxene, and occurs as an outgrowth. A few good crystals have, however, been observed, and are of the tubular form with low pyramids.

Rutile.—All the colours previously described as found in the grit are present in one or other of these separations. No geniculate or cordate twins have been found.

Zircon.—As would be expected, these in nearly all cases show good crystal outline, of the forms described for the zircons in the grit. Zonary structure is common, as are also inclusions of various forms.

Xenotime.—This is similar to the zircons in form, but is of reddish or reddish-brown colour, and somewhat larger than the majority of the zircons.

Ilmenite and leucoxene.—As was noted in the grit, ilmenite is by far the commonest of the iron-bearing minerals, and is associated with leucoxene—with anatase- and rutile-crystals as secondary outgrowths.

Tourmaline.—The long pyramid is the common form, terminated by rhombohedra in a few cases. The colour is brown to purplish, and is strongly pleochroic. Blue tourmaline has been noted in the separation from the schist.

Apatite.—As stated, this mineral has not been recorded from the grit, and is only of rare occurrence here, the form being acicular.

Topaz.—This occurs in only one of the granites, and is of irregular form, with good basal cleavage developed.

Monazite.—Its presence in these granites is most interesting. The mineral is often rounded, but one good crystal has been noted.

An interesting and important light upon the question whether the rocks of the Lake District contributed material to the Millstone Grit has been given by the work of Mr. R. H. Rastall & Mr. W. H. Wilcockson upon the accessory minerals of the Lake-District granites.[1] They find that some of the most abundant of the heavy minerals of the grit, such as rutile and tourmaline, are by no means common constituents of these granites, while sphene proves to be common in the Lake-District granites and absent from the Millstone Grit. Apatite also is common in these granites and absent from the grits, but it must be noted that it occurs in three of the pebbles from the grit. The crucial test, however, seems to be the monazite. When the paper above quoted was read before the Geological Society, Dr. H. H. Thomas, replying to the discussion on behalf of the Authors, stated that, although searched for spectroscopically, monazite had not been detected. Apart, then, from the question whether the granites of the Lake District could or could not, by reason of their exposure, have contributed material to the Millstone Grit as previously discussed, there are here definite reasons for excluding them as possible sources for the material making up the Millstone Grit Series of the Yorkshire area.

[1] Q. J. G. S. vol. lxxi (1915–17) pp. 592–622.

HEAVY MINERALS IN PEBBLES FOUND IN THE MILLSTONE GRIT.

| a=abundant. vc=very common. c=common. f=frequent. r=rare. vr=very rare. | Garnet. | Iron Pyrites. | Magnetite. | Anatase. | Rutile. | Zircon. | Xenotime. | Ilmenite and Leucoxene. | Tourmaline. | Apatite. | Topaz. | Monazite. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Granite (3 in Coll.) | ... | ... | r | f | c | a | f | c | f | vr | | |
| ,, (5 in Coll.) | f | ... | r | c | f | vc | r | a | f | r | f | r |
| ,, (10 in Coll.) | ... | ... | ... | vc | f | a | ... | vc | f | vr | ... | vr |
| ,, (11 in Coll.) | r | ... | ... | f | c | vc | ... | f | c | ... | ... | f |
| Schist (16 in Coll.) | r | ... | ... | vc | f | vc | vr | vc | Brown (Blue r) a | | | |
| ,, (18 in Coll.) | vc | a | ... | c | c | vc | .. | vc | a | | | |

We may now sum up the evidence of the lithological characters.

Pebbles of the following types have been found and examined:—Gneisses, schists (of various types), granites, pegmatites, quartz- and felspar-porphyries, quartz, felspar, quartzites, cherts, sandstones, and mudstones.

The large quartz-pebbles, which are the most plentiful of all the pebbles in the grit, are of such shape and microscopic structure as to make it certain that they have been derived from rocks which have been subjected to intense shearing, while strain-shadows are invariably present. The smaller pebbles and grains of quartz are commonly of a bluish or opalescent tint, the colour being due to inclusions of various types—regular, irregular, and acicular; while liquid inclusions with movable bubbles are exceedingly common.

The dominant felspar of all the beds is microcline. This occurs in large flesh-coloured pebbles, commonly about ½ inch in diameter, and is always quite fresh and unaltered even when it has been exposed on the face of a quarry or building for a considerable period. It occurs plentifully, too, as smaller grains in the mass of the grit or shale, where it is also quite unaltered. Other types of felspar found are microcline-microperthite, oligoclase, and a little orthoclase. The oligoclase and orthoclase are frequently altered, and I am of the opinion that the greater part of the altered felspar found in the grit has been derived from this source.

Pebbles and grains derived from sedimentary rocks are plentiful, by far the most abundant being chert (of various colours). In some of these, as already noted, traces of organisms and well-defined oolitic structure are found (see Pl. XVIII, figs. 4–6). These must represent the solution and decay of limestone-beds.

Sandstone pebbles also occur, sometimes of large size; while altered mudstone and mudstones with organisms are included in the series.

It is, moreover, worthy of note that in the coarse beds the larger grains (quartz, felspar, etc.) are frequently well rounded, while the smaller grains are always angular.

## VI. Lithological Characters of the Land-Mass from the Denudation of which the Material of the Millstone Grit was derived.

The first and by far the most important rock making up this ancient land-mass must have been a granitoid gneiss of very acid composition, which was ramified by veins of pegmatite. Unaltered granites must also have been present, but the evidence of crushing found in the great mass of the quartz of the Millstone Grit makes it quite certain that they only formed a subordinate portion of the whole mass. The dominant felspar in these rocks must have been microcline, the large pebbles of this felspar being derived from the pegmatites. The presence of mica-schist and quartz-schist, and also the abundance of mica in the shales, sometimes making up beds 2 to 3 feet thick of almost pure white mica, make it safe to infer that schists of various types constituted a large portion of the land. The garnets which are so common would in large part have been yielded by the schists. The volcanic rocks, quartz, and felspar-porphyries are significant as showing the presence of dykes of acid character, which were to be found traversing all or any of the other rocks present.

The abundance of chert-pebbles (sometimes showing oolitic structure) with cryptocrystalline and microcrystalline silica, often with rhombs representing carbonates, enable us to draw the inference that limestones containing chert-bands, and also in part silicified, were associated with the igneous and metamorphic rocks. Other sedimentary rocks, such as grits, sandstones, and mudstones, must also have been present, as pebbles of such rocks occur in the grit. Some of the rounded quartz-grains found in the grit may possibly be of contemporaneous origin; but I am strongly disposed to think that the greater number have been derived from pre-existing grits and sandstones, and therefore such types must have formed part of this ancient land-mass.

## VII. Divisions of the Millstone Grit Series.

The area occupied by the Millstone Grit Series from Derbyshire to Yorkshire was surveyed under the direction of the late Prof. A. H. Green (who formerly occupied the Chair of Geology at Leeds University). In the Memoir of the Geological Survey on the Yorkshire Coalfield, 1878, the following observations are recorded as a result of the work of the Survey (p. 27):—

'Subdivisions of the Millstone Grit in the North Central Counties.

Rough Rock—Almost invariably a coarse and massive felspathic grit about 100 feet thick. A band of flagstone frequently at the base. Called also First Grit.

Shales.

Second Grit—A somewhat variable group of finely-grained sandstones and shales.

Shales.

Third Grit—A coarse massive gritstone between 200 and 300 feet thick, remarkable for its regular jointing and bold wall-like escarpments. Fine flaggy beds at the base, and a coal on the top frequently.

Shales.

Kinderscout Grit—Coarse, often conglomeratic, very massive, with occasional bands of flagstone. Where most largely developed, in two beds with shale between. Up to 500 feet thick. Also called Fourth Grit.'

Marine bands are found at different horizons in the shales of the whole series, perhaps the most notable in Yorkshire being that exposed in Cayton Gill, north of Harrogate. When the excavations were being made for the dam of the Eccup Reservoir, Leeds, a marine band was found yielding perhaps the richest fauna yet discovered in the Millstone Grit, and I have described elsewhere a series of five such marine bands passed through in a borehole at the Tannery, Meanwood, Leeds.[1]

Coal-seams are also of frequent occurrence throughout the series, but increase in number and thickness towards the top, and have in many places been worked, though the coal is usually of inferior quality.

The subdivisions given above were found to apply well enough as the work of surveying and mapping proceeded in Derbyshire and South Yorkshire; but, as it was carried farther north, some modification had to be introduced, as it was no longer possible to identify with certainty the so-called Second and Third Grits, and it was found better to apply the term 'Middle Grits' to the large number of separate grit-beds which occur between the Kinderscout Grit and the Rough Rock. These upper and lower beds could still be identified by their lithological characters and stratigraphical position.

## VIII. Mode of Accumulation of the Material.

The assemblage of beds which make up the series is such as to leave no reasonable doubt that the material represents the deltaic deposits of some large river comparable in size with such a one as the Mississippi, and doubtless, in the same way as that great river, receiving tributaries from regions where climatic conditions were of very different types. One has only to study the literature of such deltas as those of the Mississippi, Ganges and Brahmaputra, Irrawadi, or Nile, to realize the close resemblance between such present-day deposits and the Millstone Grit of Yorkshire. Indeed, one may go so far as to say that a study of our modern deltas is absolutely essential to the understanding and correct interpretation of the problems connected with the Millstone Grit and the succeeding Coal Measures. It may be well to give an estimate of the amount of material accumulated over the area of Yorkshire

[1] Trans. Leeds Geol. Assoc. Part xviii. (To be published.)

in Millstone Grit times. The area covered in Yorkshire by this series at present is no less than 840 square miles; while if we take into account that which lies beneath the newer rocks, and that where it can be safely assumed to have occurred (but is now only represented by outliers on such hills of the Pennine Chain as Ingleborough, Whernside, Penygent, etc.), an area of 2000 square miles once occupied by Millstone Grit would be a safe assumption. If we take 1000 feet as the average thickness, this would represent 400 cubic miles; or it may be built into the form of a range of hills, which would be 800 miles long, 1 mile in diameter at the base, and 1 mile high.

Now, since it is an axiom in geology that deposition is a measure of detrition, we may form some idea of the vast amount of material which was removed from some pre-existing land-surface. This is all the more evident when it is remembered that in such an estimate as that given above, only Yorkshire has been considered, and the amount would have to be multiplied by a large factor were the Millstone Grit of other areas in the Midlands and North of England, etc., to be taken into account.

## IX. Position of the Ancient Land-Mass.

If we take first the position, the discussion will gain in clearness if a survey is taken of the Millstone Grit as it occurs in Lancashire and Yorkshire, and to the south in Staffordshire, Derbyshire, Cheshire, and Leicestershire. In papers by E. Hull and A. H. Green[1] describing the Millstone Grit of these areas, it is shown very clearly that there is a very pronounced attenuation of the series where traced towards the south and south-east. In the summary given at the end of the first paper mentioned, it is stated:—

'We have now traced the Millstone Grit from the borders of Lancashire and Yorkshire, where it contains five thick beds of massive gritstone and reaches a thickness of 2800 feet, to the borders of the North Staffordshire Coalfield, where only two of these beds are left, and where the whole thickness is not more than 200–300 feet. We find the Rough Rock ...... present everywhere and keeping pretty much the same thickness throughout, but losing altogether its coarseness and massive character in the south. The Haslingden Flags, the second bed, maintain their thickness and character unchanged until they thin away somewhat suddenly about 5 miles south-west of Buxton. The Third Grit runs through the whole of the district; but, from a thickness of more than 400 feet, which it reaches in Lancashire, it lessens down to about 100 feet in the neighbourhood of Congleton, and still further south seems to be on the point of dying out altogether. Though this bed becomes without doubt finer to the south, it keeps more than any other a certain massiveness of structure to the last ..... The passage of the fourth or Kinderscout rock from an enormous mass of gritstone and conglomerate 1000 feet thick into two beds of finer gritstone with a shale between, north of Buxton, has been pointed out, as also the further change which the latter undergo into still finer sandstones, and their total disappearance in the Biddulph and Rudyerd basins.'

The sections which are given to illustrate this attenuation are here reproduced (see fig. 1, p. 278).

[1] Q. J. G. S. vol. xx (1864) pp. 242–67; also *ibid.* vol. xxiv (1868) pp. 319–23.

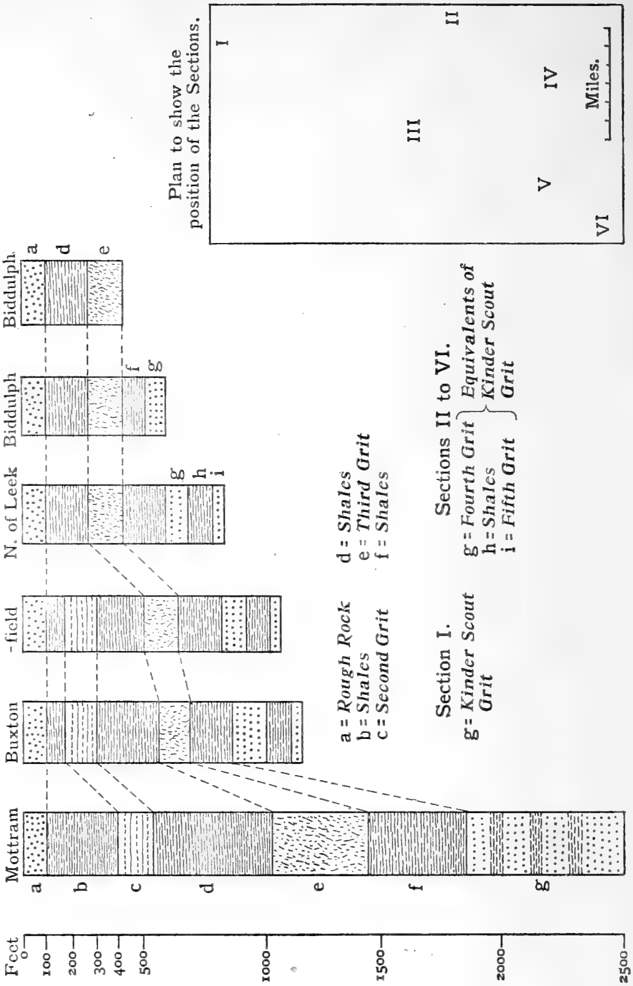



Fig. 1.—*Sections illustrating the constitution and thickness of the Millstone Grit Series in the Northern Midlands.*

In the second paper by Hull,[1] written after a more detailed examination of the district round the Pendle Range, the following comparative vertical sections are given of the Carboniferous strata from North Lancashire to Leicestershire :—

| | *Burnley District.* *Feet.* | *Mottram District.* *Feet.* | *North Staffordshire.* *Feet.* | *Leicestershire.* *Feet.* |
|---|---|---|---|---|
| Coal Measures........... | 8640 | 7635 | 6000 | 3000 |
| Millstone Grit Series ... | 5500 | 2500 | 500 | 50 |
| Yoredale Series ......... | 4675 | 2000 | 2300 | 50. |

[1] Q. J. G. S. vol. xxiv (1868) pp. 319–23.

In the Geological Survey Memoir on the Yorkshire Coalfield, 1878, the diagram (pl. i, facing p. 32) showing the variations in the grits when traced from Ashover (south-west of Chesterfield) to the neighbourhood of Skipton, makes the fact of the increase of thickness to the north very clear.

The only possible conclusion to which we can come from the facts set forth above is that the material of the grit series was derived from some northerly source.

The central barrier of St. George's Land, as it has been termed, must be excluded as a possible source for more than a small fraction of the material in the grit, for the following reasons :—

(*a*) It has not the necessary lithological character.

(*b*) The area is altogether inadequate.

In considering (*b*) it must be remembered that a large portion of the barrier which existed in Lower Carboniferous times had been covered by the encroachment of the Carboniferous Limestone. This central barrier precludes the possibility of derivation from the south of it.

The Lake District has also been cited as a possible source of supply of material, and it has been suggested that the large felspars of the grit have been derived from the Shap Granite,[1] which is quite erroneous. The recent work of Prof. E. J. Garwood[2] in mapping and zoning the Carboniferous Limestone of the North of England shows that the Lake District represented an area of subsidence in Lower Carboniferous Limestone (Avonian) times and was submerged beneath the waters of the so-called Avonian ocean.

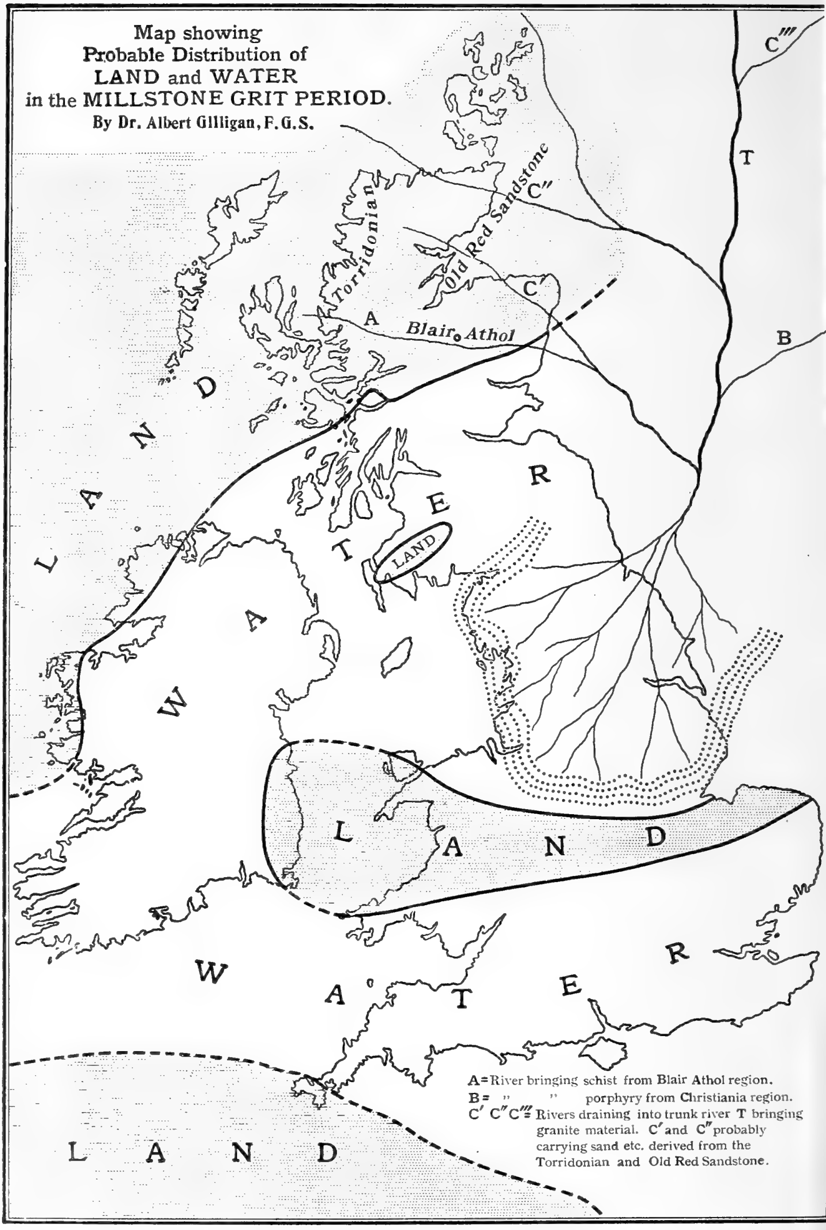
In Scotland, land was to be found in the Southern Uplands in Lower Carboniferous times, and, according to J. G. Goodchild, material derived from this area is to be found in the beds of the Basement Carboniferous of the North of England. When, however, we enquire how much of the area was exposed in Millstone Grit times after the covering of Lower Carboniferous rocks had been laid down, it is found to be quite inadequate to supply any large proportion of the Grit Series of Yorkshire, though it possibly contributed to the homotaxial deposits farther north. Here, again also, in applying the lithological test, one is bound to conclude that it rules out this area: for, while the large quartz-pebbles of the coarse grits and some of the micaceous material of the shales could have been derived in part from (or, perhaps it would be better to say, resemble some of) the rock-constituents of the Southern Uplands, the pebbles of fresh felspar and pegmatite found so abundantly in the coarse beds of the Millstone Grit most certainly did not come from that district. Also the granites forming the highest points in Galloway are notably rich in sphene, a mineral not found so far in the Grit.

By this process of elimination, I am forced to the conclusion

[1] R. D. Roberts, 'Introduction to Modern Geology' 1893, p. 244.

[2] Q. J. G. S. vol. lxviii (1912) p. 553.

Fig. 2.


Map showing
Probable Distribution of
LAND and WATER
in the MILLSTONE GRIT PERIOD.
By Dr. Albert Gilligan, F.G.S.
Torridonian
Old Red Sandstone
C″
C‴
T
C′
A
Blair Athol
B
LAND
WATER
LAND
WATER
LAND
WATER
LAND
A=River bringing schist from Blair Athol region.
B= " " porphyry from Christiania region.
C′ C″ C‴= Rivers draining into trunk river T bringing granite material. C′ and C″ probably carrying sand etc. derived from the Torridonian and Old Red Sandstone.

that the only possible area lay still farther north, in what is now the North of Scotland, and its extension lay east with a larger Scandinavia, thus forming part of a great continental land, the limits (northern and western) of which it is not at present possible to define. This is a conclusion to which previous workers in the same field have arrived, namely, Sorby,[1] and Hull,[2] while their views have been endorsed by Green.[3] The last-named quotes Sorby on this subject, and, in the map which he gives of Lower Carboniferous geography, we find that he has represented the boundary of the extension of this Scoto-Scandinavian land as lying quite close to the present eastern coastline of the Northern counties of England, crossing it at Spurn Point into Lincolnshire, and joining up with the Central Ridge before mentioned. An isthmus of the Southern Uplands connects it with a large land-mass which sends off a tongue to embrace the north of the Isle of Man and the Lake District, while another large lobe to the west takes in the North-West of Ireland. The Central Valley of Scotland forms an inlet open to the ocean in the west.

A. J. Jukes-Browne[4] criticizes this map, and proposes to join up the North of Ireland with Scotland north of the Central Valley, and to open a way between the South of Ireland and the South of England. In his own map[5] he has made these alterations, and introduces changes in the boundaries of the Central Ridge, which he connects up with Ireland and the South-West of Scotland. It is not my intention to discuss the boundaries of the Lower Carboniferous Sea: I have merely given these references and descriptions, in order to make it clear that all workers in this subject agree that the great northern land-mass did exist, and that Scotland and Scandinavia were undoubtedly connected in Carboniferous times.

Only Sorby, however, had adduced any evidence from the lithological side, and all subsequent writers to the present time have been content to quote his work, the reliability of which has never been questioned, and the result of the work herein described is to confirm the view put forward by Sorby some sixty years ago. This northern land satisfies the conditions required as to type of rock: though many of the pebbles which are here figured and described cannot be definitely traced, yet one cannot fail to be impressed with the resemblance when the whole facies is taken into account. (See map, fig. 2, p. 280.)

## X. Physical Relief of the Ancient Land-Mass.

The Carboniferous Limestone was certainly not deposited in a sea of great depth; on the contrary, it exhibits throughout its

[1] Proc. Yorks. Geol. & Polytechn. Soc. vol. iii (1859) p. 675.

[2] 'Physical History of the British Isles' 1882, p. 37; and Trans. Roy. Dublin Soc. ser. 2, vol. iii (1885) p. 305.

[3] 'Coal: its History & Uses' 1878, p. 38.

[4] 'Building of the British Isles' 2nd ed. (1892) p. 131.

[5] *Ibid.* p. 123.

whole thickness undoubted evidence of shallow-water conditions. One need only adduce as evidence of this the types of fossils which make up so large a part of the rock and the general broken condition in which they are found. The great thickness which the limestone attains in some parts is accounted for by its accumulation upon a subsiding sea-floor. Whence was the calcareous material derived? The old continental land which had been subjected to denudation during Old Red Sandstone times must have been considerably lowered by the supply of material for the formation of those beds, further it seems most probable that the rivers draining the old land would have base-levelled themselves so far, and would be draining land of such low relief, that they would no longer be able to bear along much material in suspension, and that they would have assumed the characters of old rivers in which the proportion of material in solution would be greatly increased. No doubt much of the calcium carbonate was derived from pre-existing calcareous deposits, the carbon dioxide merely acting as a carrier of the calcium carbonate from land to ocean. To this cause, that is, the solution and carrying away of the calcareous material, may be attributed the abundance of chert-pebbles found especially in the lower beds of the Millstone Grit, these representing the insoluble parts of the limestone.

But no area of pre-Carboniferous limestone would be of sufficient extent to supply the calcium carbonate in this way: much of it must, therefore, have been derived by a process of leaching, and so it seems that a great amount of carbon dioxide drawn from the atmospheric-ocean supply must be locked up in the Carboniferous Limestone. The bearing of this will be dealt with later, when the question of the climate of Millstone Grit times is discussed. Here it is sufficient to note that this process of leaching would result in a thick cover of rotted rock being left over the low ground and along the river-courses of the old continent. There is little evidence for determining the directions of the rivers of the Carboniferous Limestone period, but they must have been chiefly from the northern continent, the quantity of material accumulated rendering a large drainage-area necessary. The Yoredale Beds which succeed the Carboniferous Limestone in the North of England represent the removal of the rotted material from the old land-surface by reason of the rejuvenation of the rivers caused by uplift at the source, and its being carried forward to be spread out and deposited upon the old continental shelf upon which the lime-secreting animals of the Carboniferous Limestone period had flourished. This removal of the covering layers of the soil would prepare the land for yielding a fresh supply of unleached rock, and it is only by the upheaval of such a prepared land-surface that it seems possible to satisfy the conditions demanded by the Millstone Grit. That uplift of the great Northern Continent was taking place, producing instability and establishing a line of weakness along its southern edge, the direction and position of which is almost exactly defined by the northern edge of the Central Valley of Scotland,

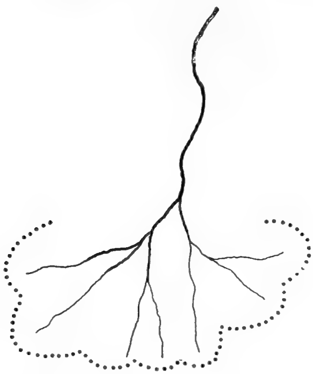
seems evident from the fact that this region, from Devonian right through Carboniferous to Permian times, was the locus of intense volcanic action. Oscillations of level and unequal subsidence are the concomitant features which we naturally find in such an area. This line was, it would seem, the limb of a great earth-fold, and the line of weakness so determined gave rise to the volcanic action cited above, as in similar circumstances we have lines of volcanoes to-day. Generally, then, the physiography of the opening stages of the Millstone Grit period may be represented by saying that folding was again taking place along the old Caledonian axes, bringing into existence a great earth-wave, the crest of which is represented by the Northern Continent and the trough by the South of Scotland, Ireland, and the North of England. That successive uplifts went on during Millstone Grit times is traceable in the fact that we have coarse beds at the base (Kinderscout), finer material in the Middle Grits, and coarse again in the Rough Rock, and in the Coal Measures we note again the fine-grained detritus succeeding the Rough Rock and comparable with the Middle Grits. It is most remarkable that the dominant constituents, both of the larger fragments and the smaller grains, should be the same in the Kinderscout Grit and in the Rough Rock, showing that the main source of supply must have been the same in both cases. With regard to the height to which the land was ridged up in the Northern Continent there is no definite evidence, but it must have been considerable, in order to cause so great a condensation of moisture as it is absolutely necessary to predicate, in order to supply the volume of water for the large rivers which transported the detritus of the Grit and Coal Measures, and it would indeed seem to me that the relief of the land must have been of Himalayan grandeur.

## XI. Drift- or Current-Bedding in the Grit.

As was pointed out by Dr. Sorby, in the paper already cited, trustworthy information as to the direction from which the material composing deltaic deposits has been brought by the rivers is afforded by an examination of the drift- or current-bedding to be found in all such deposits. It must be remembered that, in applying such a test, absolute agreement in the compass-bearing of such bedding, either in the same vertical section or over any wide area, is not to be expected, but some prevalent direction must emerge when a sufficiently large number of readings are taken. Suppose, for instance, a great river with a correspondingly extensive delta, such as the modern Mississippi. In flowing over its delta the distributaries will carry forward material in directions which make a considerable angle with the main river and with each other, as in the diagram (fig. 3, p. 284), and the angle between the two outermost distributaries may exceed 180°. Moreover, these distributaries have meandering courses, which further complicates matters. Nevertheless, in the compass-bearing of the current-bedding

the main direction of the main river will be found in a large proportion of the readings: as in the diagram, north-east to south-west, and north-west to south-east, the main direction being from north to south. Again, the distributaries will have their courses altered from time to time, and the current-bedding would not therefore be in the same direction in a vertical section. Pursuing this line of investigation, I have found, in agreement with Sorby, that the prevalent direction is north-east to south-west. Sorby made his observations in South Yorkshire, while mine have been made in Airedale, Wharfedale, and Nidderdale, as well as on outliers of grit on Ingleborough, Fountains Fell, Whernside, Bowland Knotts, Penygent, etc. The best place to make such tests is, of course, on isolated masses of grit such as can be found in plenty on the tops of the hills mentioned, as well as in the low ground in such well-known areas as Plumpton Rocks and the similar masses near Spofforth and Scriven.

Fig. 3.—*Diagram illustrating courses of distributary streams in a great river-delta.*



The frequent occurrence of beds of pebbles in such current-bedded grits as those mentioned above is of great interest, and of course they represent the heavy pebbles which have rolled down the slope of an advancing sandbank.

## XII. Comparison with the Torridon Sandstone.

As the investigation proceeded, it became increasingly evident that there was a striking similarity in composition between the Torridon Sandstone of pre-Cambrian age found in the North-West of Scotland and the Millstone Grit of the North of England. I have, therefore, had sections of the Torridon Sandstone prepared for comparison, and found a very pronounced agreement in all essential points, the most marked difference being the rounding of the grains in the Torridon Sandstone as compared with the general angularity of the grains in the Millstone Grit. One has only to read the chapter on the petrography of the 'Torridonian Formation' in the Geological Survey Memoir on the North-West Highlands of Scotland, and to compare it with the petrography of the Millstone Grit, as revealed by this investigation and here recorded, to be convinced of the strong resemblances of the two deposits.

It is, of course, natural that in the basement-beds of the Torridonian should be found pebbles derived from the underlying

formations; in fact, they represent the screes formed on the slopes of the old land-surface upon which the Torridonian rocks were laid down. The conditions which obtained during the time, and the area of deposition of the basement-beds, of the Millstone Grit, were of course quite different.

Further, complete agreement even in the general constituents of the two formations cannot be expected, since, as I have already mentioned, some part of the allothigenous material of the Millstone Grit must necessarily have been derived from rocks of later age than the Torridonian, and situated in areas which were unlikely or impossible sources of the material that makes up the Torridonian.

The following comparison will illustrate the resemblances and differences:—

| Torridonian. | Millstone Grit. |
| --- | --- |
| (*a*) Presence of blue or opalescent quartz with acicular, irregular, and regular inclusions. | (*a*) Similar pebbles abundant in the grit. |
| (*b*) The dominant felspars are microcline, microcline-microperthite, oligoclase, and orthoclase. The characteristic felspar of the arkoses is microcline and microcline-perthite, quite fresh and unaltered. | (*b*) Microcline, microcline-microperthite, oligoclase, and orthoclase occur, but microcline and microcline-perthite are by far the most abundant in the coarse grits and quite fresh to the outside. |
| (*c*) Cherts of various colours showing cryptocrystalline or microcrystalline structure. No definite organisms have yet been found. | (*c*) Cherts of various colours showing similar structure are common in the coarse beds. Some ghosts of organisms are found in a few of the chert-pebbles. |
| (*d*) Silicified oolite, in which the oolitic grains are defined by small spherical bodies and pseudomorphs in the form of rhombs showing their derivation from calcareous rocks. | (*d*) Exactly similar pebbles have been found, in which the small round bodies are about the same size as in the pebble figured and described in the N.W. Highland Memoir, p. 280 & pl. l, fig. 1. See Pl. XVIII, fig. 5. |
| (*e*) Quartzite-pebbles. | (*e*) Quartzite-pebbles. |
| (*f*) Pebbles of vein-quartz, which show evidence of shearing, are the most abundant. | (*f*) This is also the case with the Millstone Grit. See figures. |
| (*g*) In the larger pebbles are found felsites, gneiss, mica-schist. | (*g*) Pebbles of similar types are here figured from the Grit. |
| (*h*) Clastic micas (both brown and white) are present in the finer-grained beds. | (*h*) Clastic micas (both brown and white) are present in the finer-grained beds; sometimes the white mica makes up beds from 2 to 3 feet thick with only a small admixture of quartz, felspar, and oxide of iron (*e.g.*, below the Rough Rock, Keighley Moor). |
| (*i*) The heavy minerals include magnetite, ilmenite, sphene, garnet, tourmaline, zircon, and rutile; Dr. T. O. Bosworth (Rep. Brit. Assoc. Dundee, 1912, p. 474) points out the great abundance of garnet and zircon. | (*i*) The heavy minerals include ilmenite and leucoxene, garnet, zircon, tourmaline, rutile, and monazite. Of these by far the most abundant is garnet; while zircon is very common in all the beds, but especially in the Middle Grits and Rough Rock. |

The Torridon Sandstone is believed to have come mainly from the north-west, the abundance of microcline making it impossible that it should have been derived for the greater part from the underlying Archæan rocks, while it also contains pebbles of rocks which do not occur in Scotland. If that deduction be correct (as I believe it is) for the derivation of the Torridonian, then it would also appear that here is confirmation of the conclusions already arrived at from other evidence with regard to the source of material of the Millstone Grit.

Further, it must be mentioned that the Sparagmite of Scandinavia is a group of red arkoses and sandstones some thousands of feet thick, and is found over a great extent of country north of Christiania. It bears a striking resemblance to the Torridonian of Scotland, and was in all probability derived from the same source. It appears that the chief point of difference between the Torridonian and the Millstone Grit is due to the mode by which these two series of beds were accumulated. It is now agreed that the Torridonian Series represents a continental deposit, thereby accounting for the evidence of wind-action which it yields in the rounding of the grains and the presence of 'dreikanter.' The Millstone Grit, on the other hand, is undoubtedly an ordinary deltaic deposit, having been borne along with great rapidity by large rivers, of which it represents the coterminous deltas. Some of the beds of Millstone Grit which are stained red, such as the Plumpton and Follifoot Grit near Knaresborough, are sufficiently like the Torridonian to deceive anyone when examined in a hand-specimen, but a lens reveals the better rounding of the grains in the Torridonian.

If we assume, then, a river fed by streams rising among the mountains to the north, possibly fed in many cases by the melt-waters of glaciers descending from the snow-fields, such a river would receive tributaries on both banks, bringing in material from the Grampian Highlands and Scandinavia, as well as from the Southern Uplands, and possibly of land which occupied what is now the North Sea. These tributaries from Scotland and Scandinavia can be traced on the evidence of the black schist from Blair Athol, and on that supplied by the felspar-porphyry which is probably one of the facies of rhomb-porphyry of the Christiania region described previously. The old river first debouched into the Carboniferous Sea somewhere off the coast of North-Eastern England, laying down the beginnings of its delta, possibly in Lower Carboniferous times. With the first uplift of the Northern Continent the carrying power of this river increased, while its tributaries again became active agents in removing the material as previously suggested. The engrafting of the tributaries upon the larger river would take place as the deltas grew.

## XIII. Climatic Conditions.

In all considerations of ancient climates the distribution of land and water must play an important part, as was long ago pointed out by Humboldt and Lyell, for it is the deep circulation brought about by Polar currents and the corresponding spreading of the equatorial waters towards the Poles which are the fundamental elements in bringing about equable distribution of surface temperatures. How may this be applied to the Millstone Grit period? If the conclusions at which I have arrived with regard to the uplift of this great Northern Continent be correct, then the epicontinental area upon which the lime-secreting animals of the Lower Carboniferous had existed would have been considerably reduced, and a southward recession of the northern boundary of the ocean must have followed. Dr. A. Vaughan has shown[1] that such a recession is observable in South Wales. The Lower Tournaisian shore is represented on the map drawn up to illustrate his paper as an embayment connected with the south-western channel, which at its northern limit extended to the Clee Hills. In Upper Viséan times the shore-line of the south-western channel ran just north of Bristol and continued in a straight line to Pembroke. The whole neck of land which contained the 'Barrier' shifted with a wave-like motion southwards as Viséan times proceeded. Whether this uplift of land excluded the oceanic waters altogether from the circumpolar regions at any time is not clear. The collections made by Col. H. W. Feilden, of the Nares Polar Expedition, and described by R. Etheridge,[2] obtained chiefly from lat. 82° 40′ N., clearly established the occurrence in these high latitudes of Carboniferous Limestone rocks. The facies is North American and Canadian, although many of the species are British.

In the paper by Col. Feilden and C. E. De Rance (*op. cit.*), it is stated

> 'that a continuation of the direction of the known strike of the limestones of Feilden Peninsula, carried over the Polar area, passes through the neighbourhood of Spitsbergen, where this formation occurs, and contains certain species identical with those of the Grinnell-Land rocks of this horizon.' (P. 560.)

The explanation of the presence here of Carboniferous Limestone is somewhat difficult, except that it may be accounted for by an opening from the Carboniferous ocean of North America, so giving communication for the passage of those species which are identical with those of the Carboniferous Limestone of North America.

Etheridge, in the paper above cited, pp. 573–74, says:—

> 'No Triassic strata have been detected either in this or any previous expedition; whether, therefore, either the Permian and Trias seas, or both, aided in the denudation of the Carboniferous group, or their sediments were deposited and then denuded before the deposition of the Lias, which rests upon the Eglinton-Island Carboniferous Limestone, must still remain an undetermined question. It would therefore almost appear that it must have

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[1] 'Avonian Shore-Lines' Rep. Brit. Assoc. Manchester, 1915, pp. 429–31.

[2] Q. J. G. S. vol. xxxiv (1878) pp. 568–639.

been a continental land through elevation of the Carboniferous group, until the northern extension of the Liassic seas to these high latitudes. The complete absence (so far as we know) of Permian and Triassic strata in the Parry or Northern archipelago goes far to confirm this. Not a trace of any organic remains younger than the Carboniferous Limestone and older than the Miocene has occurred to Feilden and Hart, or to any of the other explorers during their researches in these high latitudes.'

This uplift of the northern area at the close of Carboniferous Limestone times premised by Etheridge is fully corroborative of the general uplift of continental dimensions which is certainly demanded by the Millstone Grit Series, and therefore the closing of the gulfs or fiords would naturally follow. That the same southward recession of the shore-line took place on the western side of the Atlantic, in America, is quite clear, for there the Mississippian or Lower Carboniferous is overlain by the Pottsville Conglomerate (the deposit which is homotaxial with our Millstone Grit) in the east, which grades westwards and south-westwards into sandstones, and with local conglomeratic phases the sandstone is found over the interior of the continent. This conglomerate and sandstone is composed of material derived from the Archæan which lay to the north. It is thought that the conglomeratic beds of the east represent the earlier stages of the epoch, and that, as the period of deposition was prolonged, the detrital material spread westwards and southwards. The analogy, therefore, with Britain would seem to be complete. Chamberlin & Salisbury have estimated that the sea was excluded from an area of about 20,000,000 square miles at the close of the Carboniferous Limestone period.[1]

The physical conditions of the Millstone Grit period with the high land to the north, probably forming a continuous belt for some thousands of miles from Europe across the Atlantic, and embracing part of Northern America, with deltas encroaching upon the ocean to the south, would determine a climate of a monsoon type. The warm southerly winds would bear an abundance of water-vapour to be condensed on ascending the slopes of the high land and capable of feeding the great rivers of this period, which in their rejuvenation would soon clear off all the rotted rock left by the leaching processes of the preceding period. The relief of the land previously discussed may have been such as to nourish an icefield and its attendant glacial phenomena; but the snow-line would necessarily be at a fairly-high altitude, on account of the proximity of the warm southern ocean and the warm winds which would blow therefrom.

Weathering of the rocks would be chiefly by mechanical means, in which chemical action played a minor part. As was first pointed out by the geologists of the Indian Survey,[2] it is possible to determine whether mechanical or chemical agents have been the

[1] T. C. Chamberlin & R. D. Salisbury, 'Geology: Earth History' vol. ii (1906) pp. 658–59.

[2] H. B. Medlicott & W. T. Blanford, 'Manual of the Geology of India' 2nd ed. by R. D. Oldham (1893) p. 201.

most active in causing the break-up of a granitic rock by an examination of the felspars found in deposits resulting from such action. If the felspars are fresh and unaltered, the inference is that the break-up of the original rock has been brought about by mechanical means. The freshness of the felspars in the deposits at the foot of the Himalayas and in the Gangetic basin they believed was due to the disintegration of the parent rock by frost and ice. J. W. Judd, in his descriptions of the Nile deposits, speaks of the freshness of the felspars,[1] and points to the area from which they have been derived as undergoing disintegration by the unequal expansion of the minerals of the rocks consequent upon the heat of the sun by day and the subsequent cooling by radiation at night. From the commencement of my investigations the exceeding freshness of the felspars of the Millstone Grit has been one of the main points which has been quite clear. Many of the photographs accompanying the present paper show this, and there can be no question of subsequent formation within the grit itself. Even in the minute fragments found in some of the finer-grained beds, which would, of course, be more easily affected than the large ones on account of the proportionately larger surface, many of these plagioclase felspars show no trace of decomposition. The microcline is indeed well known to be the most resistant of the felspars: in all the grits this felspar occurs, both in the large pebbles and in the small grains, in the most perfectly fresh condition, and when a large pebble is fractured the cleavage-faces are often as bright and lustrous as possible. The kaolinization noticeable in some of the grit-beds, as in the Rough Rock of Horsforth, has evidently been brought about since the rock has been exposed in post-Carboniferous times, the original outline of the felspars being usually traceable.

When discussing the source of the calcium carbonate in the Carboniferous Limestone, I pointed out that much of it must be due to leaching of calcareous material from silicates of the alkaline earths: this would necessarily mean an abstraction of the carbon dioxide from the atmospheric-oceanic supply, causing a considerable diminution in that substance. This would leave the Millstone Grit period with a much depleted supply, so that the freshness of the felspars in the Grit and the formation of the Carboniferous Limestone are in consonance one with the other, chemical agents being active in the formation of the latter and of little importance in the former. In fact, this period may be looked upon as one when the atmospheric-oceanic supply was being replenished.

As Judd, in the paper above quoted, pointed out, an examination of the clays (if modern deposits) or shales (if ancient deposits) should yield evidence of the amount of chemical decomposition which the parent rocks have undergone. If kaolin is the chief constituent, then chemical action has been responsible to a great extent; but, if

[1] Proc. Roy. Soc. vol. xxxix (1886) pp. 215–17.

they consist of the same minerals as the coarser beds, only in a finer state of subdivision, then mechanical agencies have been dominant in causing the disintegration of the original mass. I have applied this test to the shales of the Millstone Grit, and find that they are composed in a large part of mica with which are associated finely-divided quartz and felspar and an abundance of heavy minerals, such as zircons and rutile, in beds that do not carry marine fossils. These latter are quite different from the normal shales, so that in an exposed section it is possible for anyone acquainted with these marine shales to identify them at once, on account of their exceedingly fine texture, quite different from the normal shales, and on analysis they yield a greater amount of water, pointing to their composition being much more like that of kaolin than the normal shales. Was it glaciation or insolation which was more active in Millstone Grit times? There is no evidence of the former, while everything points to the latter as being extremely probable, and to this opinion I strongly incline. It may be, as previously pointed out, that the height of the old continental land was such as to nourish an icefield in the same way as at present; we have such conditions in the Himalayas. If, however, the high mountains were bordering the sea during the earlier part of the period, as would appear to have been the case, in the area under review at least, then their flanks facing south would have been kept free of ice by the proximity of the warm water laving the shore. As the deltas grew seaward the distance between the ocean and the foothills (which were continually decreasing in height by the intense denudation that they were undergoing) would be increasing, and so the climate of the same tract of country would be passing from one approximating to an insular climate to the continental type. At the same time, with the decrease in height of the hills, the area above the snow-line would decrease, especially near the shore-line, where the effects of denudation would be felt most severely. It seems to follow, therefore, that the part played by ice was a quite subordinate one, and that it was confined to the work of an icefield or several isolated icefields, the descending glaciers from which never reached very far down the mountain-valleys.

In conclusion, I wish to express my sincere thanks to those who have so kindly assisted me in many ways. To Prof. T. G. Bonney, Prof. H. L. Bowman, Prof. W. C. Brögger, Dr. Herbert H. Thomas, and Mr. George Barrow, for help in the identification of rocks and minerals; also to Dr. J. Horne, Mr. J. Holmes, and Mr. G. F. Pickering, who have generously supplied me with specimens of rock and of pebbles. To Prof. P. F. Kendall I express my thanks for his interest and helpful advice on many occasions in the long period during which the work has been in progress.

## EXPLANATION OF PLATES XV–XVIII.

### Plate XV.

Fig. 1. Quartz-pebble from Kinderscout Grit, The Strid, Bolton Abbey. The specimen is a good example of mylonitization, with evidence of shearing in the elongated patches of quartz, well seen in the photograph. × about 20 diameters. (See p. 262.)

2. Pebble of blue quartz from the Middle Grits near Ripon. The acicular inclusions are well shown, as are also the liquid inclusions which contain movable bubbles. × about 110 diameters. (See p. 254.)

3. Pebble of black quartz from the Rough Rock, Cragg-Hill Quarry, Horsforth. A very common type, the strain-shadows and 'mortar-structure' resulting from pressure prior to inclusion in the grit. × about 20 diameters.

4. Pebble of microcline from the Rough Rock, Cragg-Hill Quarry, Horsforth. × about 20 diameters. (See p. 254.)

5. Pebble of felspar from the Rough Rock, Clayton-Wood Quarry, Horsforth. This also is a common type, consisting of a microperthitic intergrowth of microcline and oligoclase. × about 20 diameters. (See p. 254.)

6. Kinderscout Grit, Embsay Moor, near Bolton Abbey. The freshness and rounding of the microcline is noticeable, and the term 'arkose' is correctly applied to such a rock.

### Plate XVI.

Fig. 1. Rough Rock from borehole, at a depth of 125 feet, Meanwood, Leeds. Fresh plagioclase felspar is uncommon. × about 20 diameters. (See p. 262.)

2. Pebble of quartz-porphyry, from the Middle Grits, Silsden. The ground-mass shows traces of devitrification, and the quartz is often much corroded. × about 20 diameters. (See p. 256.)

3. Pebble of quartz-porphyry from the Middle Grits, Silsden. This differs in type from that illustrated in fig. 2, in that it contains much decomposed and corroded orthoclase. × about 20 diameters. (See p. 256.)

4. Pebble of porphyry from the Middle Grits, Silsden. In the ground-mass quartz and felspar occur in micrographic intergrowth of an extremely minute character. The felspars are chiefly albite and oligoclase, with some orthoclase. × about 25 diameters. (See p. 256.)

5. Pebble of pegmatite, from the Kinderscout Grit, Skipton. Pegmatite consisting of quartz intimately intergrown with microcline (which is very fresh) and microperthite. × about 20 diameters. (See p. 255.)

6. Pebble of pegmatite from the Rough Rock, Cragg-Hill Quarry, Horsforth. In the hand-specimen the quartz appears opalescent, and shows under the microscope inclusions similar to those seen in Pl. XV, fig. 2. The dark areas with good crystal outline are caused by the removal of felspars during the slicing process. × about 20 diameters. (See p. 255.)

### Plate XVII.

Fig. 1. Pebble of granite from the Middle Grits, Silsden. This is the largest pebble yet obtained from the Millstone Grit, measuring 10 by 8 by 4 inches. It is of a general pink colour, with large white and grey patches of altered felspars. Hornblende and biotite both much altered, with separation of iron-oxides. The biotite has numerous small zircons enclosed. × about 25 diameters. (See p. 255.)

Fig. 2. Pebble of granite from the Middle Grits, Silsden. The felspar is oligoclase, very fresh, often enclosing quartz. A little hornblende is present. × about 25 diameters. (See p. 255.)

3. Pebble of granite from the Middle Grits, Silsden. Quartz (opalescent), fresh felspar, and muscovite are distinguishable in the hand-specimen. The felspar shows curved lamellæ, and encloses blebs of quartz. × about 25 diameters. (See p. 255.)

4. Pebble of granite from the Middle Grits, Silsden. This appears to be a fine-grained felspathic gneiss, but under the microscope shows no trace of having been crushed. The rock is a protoclastic granite, singularly fresh. × about 25 diameters. (See p. 256.)

5. Pebble of quartz which encloses a fragment of mica-schist, from the Middle Grits, Silsden. The quartz bears evidence of shearing. The mica-schist is of the usual type. Vermicular chlorite occurs in the quartz. × about 20 diameters. (See p. 256.)

6. Pebble of mica-schist, very much contorted, from the Middle Grits, Silsden. Garnets with good crystal outline are present, but frequently part of the garnet has been replaced by some other isotropic mineral which has not been determined. × about 20 diameters. (See p. 256.)

## Plate XVIII.

Fig. 1. Pebble of black lustrous mica-schist from the Middle Grits, Silsden. Magnetite has separated out prior to the final folding, as it has conformed so well with the lines of folding. Quartz is fairly abundant, while no fresh felspar can be detected. × about 25 diameters. (See p. 257.)

2. Pebble of black lustrous mica-schist from the Middle Grits, Silsden. Quartz is fairly abundant. Muscovite and biotite are the principal constituents, together with a white chlorite. Much black dust occurs in the felspars. This is the pebble identified as the Black Schist of the Blair Athol-a-Nain district. × about 25 diameters. (See p. 257.)

3. Pebble of greenish slaty rock, with pronounced folding, from the Middle Grits, Silsden. The most noticeable feature is the beautiful microfoliation with a tendency to strain-slip cleavage. × about 25 diameters. (See p. 257.)

4. Pebble of black chert from the Kinderscout Grit, The Strid, Bolton Abbey. A fine-grained chert, deeply stained with iron-oxide and in part isotropic. One edge shows typical oolitic structure. × about 25 diameters. (See p. 257.)

5. Pebble of grey chert from the Plumpton Grit, Knaresborough. The oolitic grains have their borders defined by a number of small rounded bodies, which do not show any organic structure. Numbers of these bodies occur scattered through the rock apart from the oolitic grains. The section bears a striking resemblance to a pebble from the Torridon Sandstone, described in the North-West Highland Memoir, p. 280 & pl. l, fig. 1. × about 25 diameters. (See p. 257.)

6. Pebble of black chert from the Rough Rock, Cragg-Hill Quarry, Horsforth. By ordinary light outlines of organisms can be seen, probably sponge-spicules. In polarized light no trace of these organisms can be seen, and the rock appears to be made up of small grains of quartz embedded in a fine-grained siliceous matrix. × about 25 diameters. (See p. 258.)

## Discussion.

The Secretary read the following remarks, received from Dr. B. N. Peach :—

'I had the opportunity of reading the Author's MS. on 'The Petrography of the Millstone Grit Series of Yorkshire' when it was presented as a thesis for the D.Sc. degree at Leeds University. I was impressed with the exhaustive character of the research and the thoroughness of the Author's detailed methods. His investigations throw much light on the petrographical characters of these coarse sediments and the probable region from which the main constituents were derived. I agree generally with his conclusions. He has established, in my opinion, that a great part of the constituents of the Yorkshire Millstone Grit closely resemble those found in the Torridonian arkoses of the North-West Highlands. It seems a reasonable conclusion that the materials in this deltaic deposit in Yorkshire were borne by a great river, from a continental land-area in the North where granitic rocks were exposed to denudation similar to those that supplied the abundant microcline in the Torridon Sandstone. The abundance of optically-strained quartz-grains, the micas, the pebbles of chloritoid rock and rhomb-porphyry suggest that the river flowed over, or received tributaries from, a region which is now Scotland on the one side and Scandinavia on the other. This conjecture is greatly strengthened by the study of the heavy-residue minerals, especially of the rare monazite, which the researches of Dr. Mackie of Elgin have proved to be comparatively common in the schists and pre-Carboniferous granites of Scotland.'

Dr. H. Lapworth asked whether the Author's researches had enabled him to distinguish the various grit horizons that made up the series. In North Derbyshire the speaker found little difficulty in recognizing and separating the lower grits one from the other in the field; but in Yorkshire and other areas the individual beds appeared to have no marked characteristics.

Dr. H. H. Thomas said that he was deeply interested in the work that the Author had carried out. He was especially impressed with the extreme abundance, relatively speaking, of certain of the heavy detrital minerals described, more especially of monazite; for, although the speaker had proved that it was of fairly general occurrence, having found it in the alluvium of the Trent, in the blown-sands of the Hampshire Coast, and the Irish-Sea Drift of Wales, the amount obtained was always inconsiderable. The speaker congratulated the Author, and expressed the opinion that the communication which had just been made to the Society constituted the most complete account of the petrography of a sedimentary series that had ever yet been published.

Mr. W. H. Wilcockson asked whether the Author had detected any trace of pyrrhotite in the Millstone Grit. In work on the sandstones in the Denbighshire Grit Series of North Wales, the speaker had found this mineral in fair quantity in several of the coarser grits, such as the Corwen and Pen-y-Celog-Grits, and that not only in the unweathered parts, but in the bleached surface-layers. In the Welsh grits these layers contained specks of iron-oxide, which seemed to have resulted from the decomposition of some of the sulphide mineral, and similar specks of iron-oxide

were noticeable in the weathered portion of some of the Millstone Grits.

The President (Mr. G. W. Lamplugh), in closing the Discussion, asked whether the Author's investigations had yet been extended to the sandstones of the Jurassic area in the North Riding of Yorkshire.

The Author, after thanking the Fellows for their kind reception of his paper, said that work upon the rocks of the Jurassic System of Yorkshire was just being taken up at Leeds University, and it was proposed to examine, in due course, the Estuarine Sandstones, which offer problems similar to those dealt with in the paper. Answering Dr. Lapworth's question, he said that correlation of the lenticular sandstone and grit-beds of Central and Northern Yorkshire had not been definitely attempted; but he was convinced of the use of such methods for that purpose, in the same way as had been attempted by Dr. T. O. Bosworth for the sandstones of Carboniferous age in Scotland. Dr. Thomas's statement regarding the widespread distribution of monazite in recent deposits was of great interest, and he hoped that its source would be definitely traced. Pyrrhotite had not so far been discovered in the beds of the Millstone Grit Series, but abundant sulphide of iron occurred in the Coal-Measure Sandstones, and it was quite possible that some of this was pyrrhotite.

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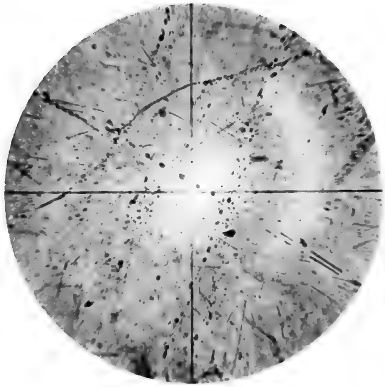

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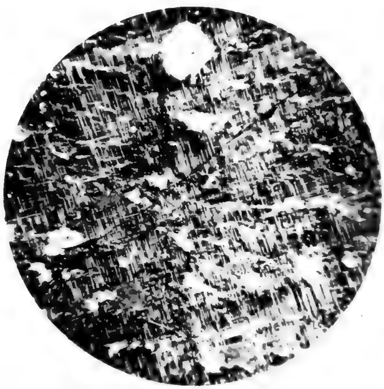

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A.G., Microphoto.

Bemrose, Collo. Derby.

PEBBLES FROM THE MILLSTONE GRIT OF YORKSHIRE.

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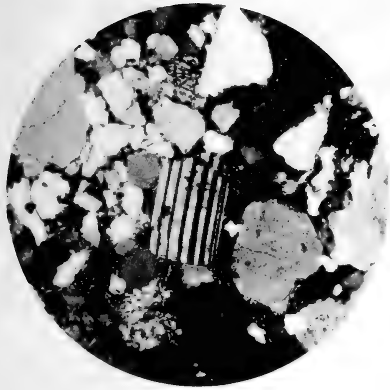

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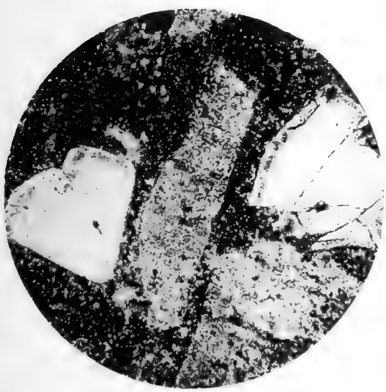

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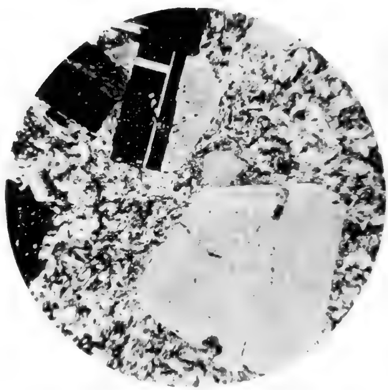

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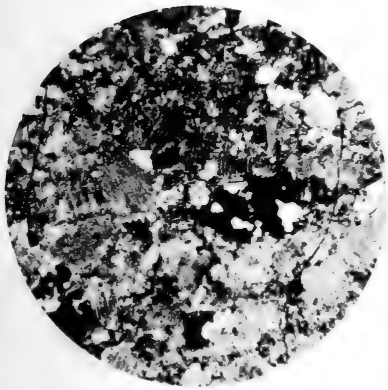

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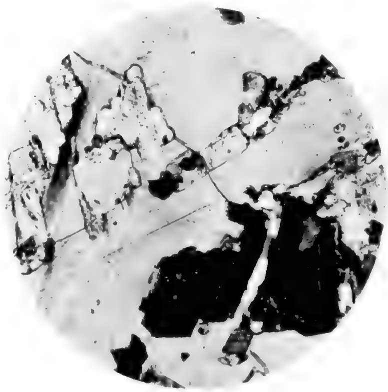

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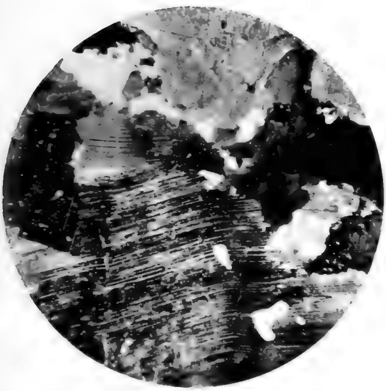

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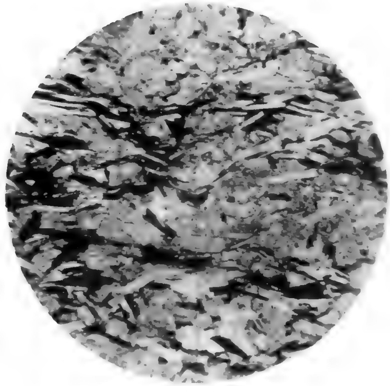

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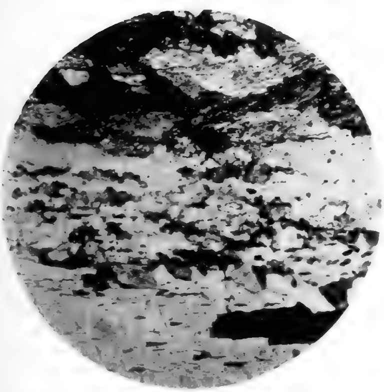

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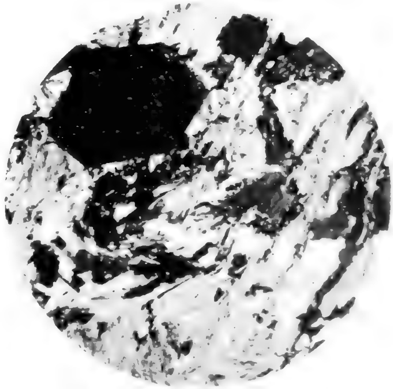

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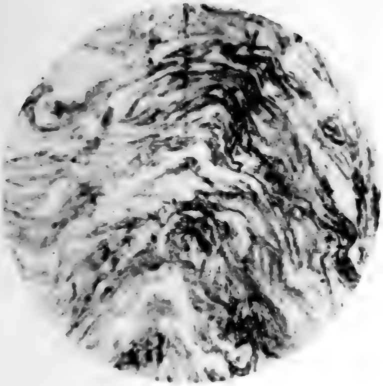

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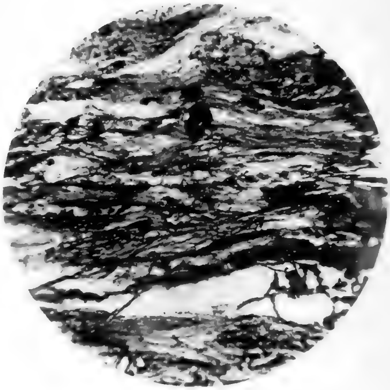

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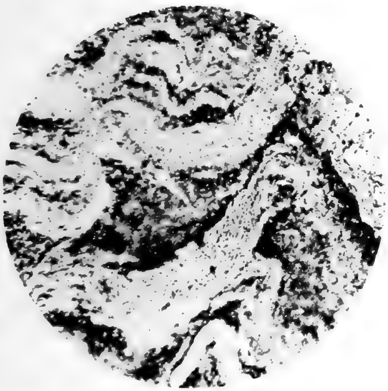

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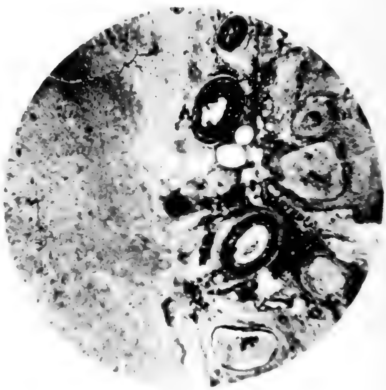

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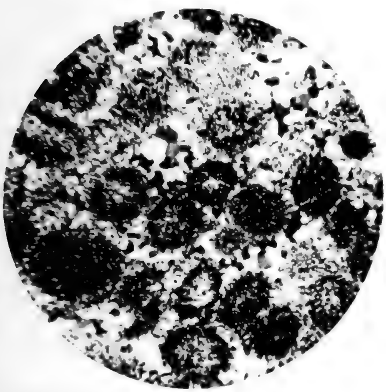

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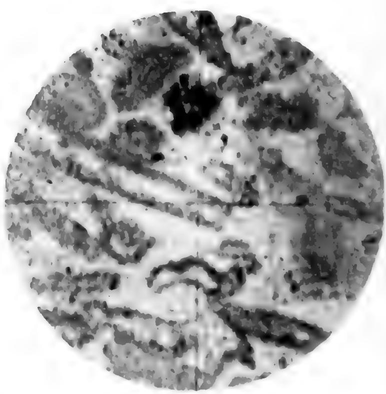

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PEBBLES FROM THE MILLSTONE GRIT OF YORKSHIRE.

# GENERAL INDEX

TO

# THE QUARTERLY JOURNAL

AND

# PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXXV.

[**August 17th, 1920.**]

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

## ADMISSION AND PRIVILEGES

OF

## FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

EVERY Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

Fellows on election pay an Admission Fee of Six Guineas. The Annual Contribution paid by Fellows is Three Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may, at any time, be compounded for by a payment of Fifty-two Pounds Ten Shillings.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open on Week Days to the Fellows between the hours of 10 and 5 (except on Saturdays, when the hours are from 10 to 1, and except during the fortnight commencing on the first Monday in September, see also next page). Under certain restrictions, Fellows are allowed to borrow books from the Library.

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## PAPERS READ.



[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library at the Apartments of the Society is open every Week Day from Ten o'clock until Five, except on Saturdays (when the hours are from 10 to 1), and except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning.

**The Secretaries of the Society are desirous of completing a record of the services rendered by the Fellows in connexion with the War. Details of service, with a statement of rank, regiment, military honours, and any other information, will be gladly received from Fellows, either with reference to themselves or to those known to them.**